A BRIEF COURSE
IN
PHYSICS

HOADLEY

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Physics
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A BRIEF COURSE

IN

GENERAL PHYSICS

EXPERIMENTAL AND APPLIED

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BY

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"Education is the cultivation and development of thinking power." — DWIGHT

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HOADLEY'S PHYSICS.

W. P. 13

PREFACE

To insure the greatest benefit from the study of Physics, there should be a coördination of (*a*) a reliable text, (*b*) class demonstrations of stated laws, (*c*) practical questions and problems on the application of these laws, and (*d*) personal experimentation in the laboratory. A thorough study of the text is necessary, for by this means only can the pupil secure for himself the knowledge that has been attained by the scientific men who have preceded him; there should be illustrative experiments, or demonstrations, to show the application of recognized laws, or the methods by which they have been established; there should be practical questions and problems to train the thinking power and to show that the principles of Physics are the foundation of a multitude of natural phenomena; and there should be laboratory work to train the observing power and to teach the unvarying relation between physical causes and their effects.

My purpose has been to provide a book that can be completed with a reasonable amount of work within an academic year; to present the different phases of the subject in as logical a manner as possible; and to introduce such experiments as can be made with comparatively simple forms of apparatus.

While avoiding the undue prominence of any one division of the subject, it has seemed proper to lay stress upon the mechanical principles which underlie the whole; upon the curve as the only universal scientific method of expressing the results of an experiment, and upon the measurement of electrical quantities and the application of the electrical current.

In the Appendix will be found a few additional experiments, for the convenience of those who wish to meet, technically, the published requirements for entrance to Harvard, the recommendations of the National Educational Association, or those of the College Entrance Examination Board for the Association of Colleges and Preparatory Schools of the Middle States and Maryland, — all of these recommendations being identical.

Numerical answers to problems will be found on pages 447 and 448. They are inserted to make easy the verification of the student's accuracy in solving the numerical problems; but as they are printed on one leaf they can be removed from the book without injury, if desired.

GEORGE A. HOADLEY.

Swarthmore College

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A BRIEF COURSE IN PHYSICS

INTRODUCTORY

1. Physics is that *science of matter and energy* which has for its object the investigation of the laws that express the relation between *physical phenomena* and their *causes*.

In order to study and formulate these laws the student makes use of experiments in which various changes in the conditions may be made and their results noted.

2. Matter is that which *occupies space* and may be perceived by one or more of the senses. There are various kinds of matter, called **Substances**, such as wood, stone, water, air, etc., while **Bodies** are composed of definite volumes of these substances.

3. Atoms and Molecules. — The fact that bodies can be compressed gave rise to the belief that the space they occupy is not filled entirely by the matter of which they are composed, and that its particles do not really touch one another. These particles are called *molecules*, and they are the smallest parts into which a body can be divided without destroying the substance as such. If the forces which keep the molecule intact are overcome, the molecule may be broken up into *atoms*, which are understood to be the smallest quantities of matter that can enter into combination. For example, one molecule of water, H_2O, contains two atoms of hydrogen and one of oxygen. The name *corpuscle* has been given to particles of matter smaller than the atom, which act as carriers of negative electricity.

The term molecule is a convenient one for the *physical unit* of matter, as the term atom is useful for the *chemical unit.*

4. Size of Molecules. — Molecules are so small that they cannot be seen by microscopes of the highest power. Lord Kelvin (Sir William Thomson) has, however, calculated their size in some substances, and from a study of the thickness of the film in soap bubbles he concludes that if a globe of water the size of a football were magnified to the size of the earth, the molecules would occupy spaces intermediate in size between small shot and footballs.

The number of molecules in a cubic centimeter of gas at the ordinary temperature and pressure is given by Maxwell as about 19,000,000,000,000,000,000. This means that if a bottle holding 1 cu. in. were filled with air, and it should escape at the rate of 100,000,000 molecules per second, it would take nearly 100,000 years for all the air to leave the bottle.

5. States of Matter. — In the air we breathe, the water we drink, and the bread we eat we have examples of the three different forms or states that matter can assume; namely, *gaseous*, *liquid*, and *solid*. A **Solid** is a body which, at ordinary temperatures and under slight pressures, does not change its shape. If the shape is changed under these conditions, the body is a **Fluid**. Fluids may be divided into two classes. Those that retain a definite surface on being poured into a vessel are **Liquids**, while those that have a tendency to expand indefinitely are **Gases**. Fluids flow: it is commonly supposed that solids do not. This is not strictly true, since it has been shown that under certain pressures solid bodies also flow, as in the case of iron when disks are punched from boiler plates by hydraulic pressure.

The state of matter is largely determined by conditions of temperature and pressure.

A stick of sealing wax fastened at one end so that it will stand horizontally, and having a two-pound weight attached to the other end, will become permanently bent in a short time; an asphalt pavement on a sloping street will flow down hill in a hot day; and a bullet placed upon a cake of shoemaker's wax, resting upon two corks in a dish of water, will in a few months pass entirely through the wax, while the corks will pass upward into it. All these are examples of what are called solid bodies, yet under the proper conditions they are seen to flow.

Bodies form an almost continuous gradation from the most rigid solid to the most tenuous gas, and the above classification may be extended as in the following table:

Rigid solid	Steel
Soft solid	Putty
Viscous liquid	Tar
Mobile liquid	Water
Vapor	Vapor of water
Gas	Air

Some substances assume all three states through a change of temperature alone, as water, which may be solid (ice), liquid (water), and gaseous (dry steam). Others require a change of pressure as well as a change of temperature.

6. **Energy** may be called the *power of doing work.* The ram of a pile driver falling upon the head of the pile forces it into the ground to a depth which depends upon the weight and the height from which it falls. Increase either, and its power of doing work, that is, its energy, is

increased, and the pile is driven further into the ground. By winding a watch, enough energy is stored in its coiled spring to keep the watch running for the entire day.

7. Physical and Chemical Changes. — The *physical phenomena* whose laws of relation we are to investigate are the result of *physical changes.* Whenever a change takes place in matter without destroying the identity of the substance, it is known as a **Physical Change**. The fall of a stone thrown into the air, the changing of water into steam, the shrinking of a board while seasoning, the attraction between a magnet and a nail, are all physical phenomena, and the changes that take place are physical changes. If, however, the water is separated into the gases hydrogen and oxygen, or the board is burned, or the iron nail is eaten by acids, the identity of the substance is destroyed, and the change is a **Chemical Change.**

8. Experiments. — An experiment is a question put to nature, and the results obtained by it are her answer. It has been the common experience of men that to the same question nature always gives the same answer, and thus we learn that *the order of nature is constant;* or that she has definite laws by which she works. A careful study of the experiments which follow, attended by the actual making of them by the student, will show in how great variety the questions can be asked and what is the effect of every changed condition. In the interpretation of the results of an experiment **Hypotheses** are formed to explain these results. When these are found to account satisfactorily for all the observed facts, they become accepted **Theories**; when these theories are established so firmly that they cannot be overthrown, they are the expression of **Physical Law.**

CHAPTER I

PHYSICAL FORCES AND UNITS

9. Forces. — All physical phenomena are caused by *physical forces*. In physics the term *force* is used to denote that which *tends* to produce, to change, or to destroy the motion of a body. The action of a boy pushing against a tree, though it may not produce motion, yet tends to do so, and hence is a force.

10. Classes of Force and Motion. — Forces may be classified in various ways: there are *molar*, *molecular*, and *atomic* forces. A molar (mass) force is one which exists between bodies that are at a sensible distance from each other, while molecular and atomic forces exist, respectively, between molecules and between atoms, at insensible distances. Molar forces may be classified as

1. *Attractive forces*, such as gravitation; and
2. *Repellent forces*, such as the repulsion that takes place when like poles of two magnetic needles are brought near each other.

They are also classified as

1. *Continuous forces*, which act without cessation for a given time, and of which there may be two kinds, — *uniform forces*, which are always the same in intensity, and *variable forces*, which are constantly changing in intensity; and
2. *Impulsive forces*, which act for a short time only.

11. Measurements. — The modern study of physics and the accurate knowledge obtained therefrom have been largely the result of the use of precise measurements; these measurements have been made in the units of mass, space, and time.

12. Space of One Dimension: Length. — We shall consider two systems of measurements, the English because it is in general use, and the French or metric because of its simplicity and of its growing use in all scientific work.

The English unit of length is the *yard*, which is by law defined as "the distance between the centers of the transverse lines, in the two gold plugs in the bronze bar deposited in the office of the exchequer," in London. Since a standard of any kind must be invariable, and since a change in temperature affects the length of a metal bar, the temperature at which this distance is the standard of length must be fixed. This temperature is 62° Fahrenheit.

Copies of this standard have been made and distributed to those countries that use the English system. The standard yard in the United States is, however, derived from the National Prototype Meter which was received from the International Bureau of Weights and Measures near Paris. This scale is made of an alloy of platinum with 10 per cent of iridium.

For practical use the *foot* — one third of a yard — is taken as the unit.

The French unit of length, the *meter*, was devised by physicists in the latter part of the eighteenth century, to accomplish two things: first, to obtain a unit that would have a natural measure for its basis; and second, to take advantage of the convenience of the decimal scale. To secure the first result the 10-millionth part of the distance from the equator to the pole, measured on the meridian passing through Paris, was taken as the unit of length. Subsequent and more accurate measurements have shown that the distance as originally measured was not absolutely correct, and that the length of the standard meter is contained in the quadrant of the earth 10,000,880 times. While this prevents the meter from being the decimal part of a natural unit, it does not affect the value of the meter as a practical unit.

The standard meter is a rod of platinum kept in the archives at Paris, and the distance between its ends at the temperature of melting ice is 1 m.

For the multiples of the meter the Greek prefixes *deka*, *hekto*, etc., are used, and for the decimal parts the Latin prefixes *deci*, *centi*, etc.; this is shown in the following table:

10 millimeters = 1 centimeter
10 centimeters = 1 decimeter
10 decimeters = 1 meter
10 meters = 1 dekameter
10 dekameters = 1 hektometer
10 hektometers = 1 kilometer

The relation between the divisions of the meter and the foot is shown below:

1 mm. = .03937 inch
1 cm. = .3937 inch
1 dm. = 3.937 inches
1 m. = 39.37043 inches
1 Dm. = 32.809 feet
1 Hm. = 328.09 feet
1 Km. = 3280.9 feet = .621 mile

The student will find it useful to become familiar with a few approximate values besides the exact value of the meter in inches. The millimeter is nearly equal to $\frac{1}{25}$ of an inch, the decimeter to 4 inches, the kilometer to $\frac{5}{8}$ of a mile, and the inch to 2.54 cm.

To use any scale intelligently one must have a distinct idea of the values of the units of measure. To secure this in the metric scale the student should measure a great many familiar objects with the metric scale in terms of the centimeter, as that is commonly taken as the physical unit of length.

13. Space of Two Dimensions: Surfaces. — Since a surface has but two dimensions, the unit of surface is a square of which the unit of length is the side. In most physical measurements the *unit of surface* is the *square centimeter* (sq. cm.), though for small areas the square millimeter (sq. mm.) is commonly used. The table is similar to the table for length, but with a uniform scale of 100.

14. Space of Three Dimensions: Solids. — With three dimensions, length, breadth, and thickness, we have solidity. The unit of volume is a cube with the unit of length for each edge. In the metric system it is the *cubic centimeter* (c.c.), and the scale of the table is 1000.

15. Mass and Weight. — The *mass* of a body is the amount of matter there is in it, as determined by "weighing" the body in a lever balance. The *weight* of a body, though depending upon its mass, is a different thing, and the two words should not be confused. The weight of a body is *the measure of the mutual attraction between the body and the earth.* This attraction varies in degree at different parts of the earth, while the amount of matter, or *mass*, in a pound of gold, for instance, is the same everywhere.

The French *unit of mass* is the kilogram (1000 g.). The gram, which is the practical unit for physical use, is the mass of a cubic centimeter of distilled water at the temperature of its greatest density (4° Centigrade). Decimal subdivisions and multiples of the gram are named by using the same prefixes as with the meter. If the mass of a body is known in kilograms, an equivalent expression in pounds may be found. The relation is as follows:

1 Kg. = 15432.3487 grains or 2.2046 pounds.

Since at any one place the weights of bodies are directly proportional to their masses, and since the variation in weight with location on the earth's surface is not very great, the terms that are applied to masses (*gram*, *pound*, *ounce*, etc.) are commonly applied to the corresponding weights also.

16. Capacity. — Measures of capacity in the metric system depend upon the unit of length, the *unit of capacity* being a cubic decimeter, which is called the *liter*. As this is 1000 c.c., a liter of pure water at the temperature of greatest density weighs 1 kg.

17. Time. — The *unit of time* in physical work is the *second*. This is the second of mean solar time, and is $\frac{1}{86400}$ of the mean solar day.

Since the motion of the earth in its path around the sun is not uniform, the number of seconds that elapse between the time when the sun crosses a given meridian, and its crossing the next day, is not uniform, but for parts of the year is more than 86,400 seconds and for parts of the year less. This number of seconds, however, is the average time, and hence that is the length of the average solar day.

18. The C. G. S. System of Measurement. — Scientific men working in various countries felt the inconvenience of having various standards of length, mass, and time, and finally adopted the centimeter-gram-second, or C. G. S. system, for scientific work. The convenience of this system is so great that it is taking the place of the foot-pound-second, or F. P. S. system, used in Great Britain and the United States.

PROBLEMS

1. An athlete runs a quarter of a mile in 52 sec. How many meters does he go per second?

2. An express train goes 60 mi. per hour. How many kilometers will it go in two and a half hours?

3. Reduce 13.421 m. to millimeters; to centimeters; to decimeters; to feet and inches.

4. How many pounds in 18 kg.?

5. How many grams in 3 lb. 2 oz. avoirdupois? Change your answer to kilograms.

6. How many liters of water can be put into a box the interior of which is 18 cm. long, 12 cm. wide, and 9 cm. deep? What is the weight of this amount of water?

7. What must be the depth of a cylindrical vessel 8 cm. in diameter, to hold 2 l.?

8. What is your weight in kilograms?

9. Write the metric table of square measure.

10. Write the metric table of cubic measure.

19. Laboratory Work. — The great advance that has recently been made in the application of the principles of physics to the needs of modern life is the direct result of the work that has been done in physical laboratories. This work differs from that done in the class room, since it is truly experimental — a search for results that are not known — while class-room work is usually in the form of demonstration.

Experimental work must be done by the student himself, and if carefully done will prove his best teacher. A few suggestions in regard to it may be of value:

1st. *The Notebook.* — The student should be provided with a suitable notebook in which everything connected with the experiment *must* be put down as soon as it is observed. A well-kept notebook is invaluable, and its accuracy should be beyond question.

2d. *Accuracy, Carefulness, and Precision.* — If the notebook is to be accurate, the student's work upon which it is based must be accurate. If 3 g. of a substance are to be taken in an experiment, it must be 3 g., and neither 3.1 nor 2.9 g. There must also be accuracy in observation and accuracy in statement. If an experiment is to have any value, the work must be carefully done. The laws of nature make no allowances for our errors. In stating the results of an experiment the student should be clear and precise, so that the exact idea that he had in mind will be the one conveyed to the reader of his notes.

3d. *Verification.* — The student should never be satisfied to make an experiment once only. Repeat until every detail is familiar and the principle is thoroughly understood.

Although it may not be necessary for every student to make every experiment given in this book, yet every student should do the larger part of this work, and should do it understandingly; and that student will have the best grasp of the subject who does this work most conscientiously. Two things will save time and secure more satisfactory results:

1st. Read the directions for the experiment carefully and understand what the object of the experiment is before beginning work upon it: the *object*, not the *result*, for preconceived ideas of what the result should be have no place in an experiment.

2d. Adopt some general form for your notes, such as here indicated:

(*a*) Object of experiment.
(*b*) Description of method and instruments used.
(*c*) Observation of phenomena.
(*d*) Conclusion.

LABORATORY WORK

1. Make, with a sharp-pointed pencil, two dots near the opposite corners of a page in your notebook. Measure the distance between them in centimeters five times, taking different parts of your scale, and placing the scale on edge so the divisions will come close to the paper, and tabulate your results in the form shown on the next page.

No. of Ex.	Dot A.	Dot B.	Distance
1	2 cm.	27.31 cm.	25.31 cm.
2	3 "	28.30 "	25.30 "
3	5 "	30.29 "	25.29 "
4	8 "	33.32 "	25.32 "
5	7.3 "	32.59 "	25.29 "
		5	126.51 cm.
			Average = 25.302 cm.

In this table the second and third columns show the direct readings, and the fourth gives the distance, which is a derived result. The average result of the five readings gives the true distance between the points. The differences in distance shown in the fourth column in this assumed experiment are greater than would be found except with an inaccurate scale.

As the first decimal figure in the third column represents millimeters, — the smallest division on your scale, — the second decimal figure is your estimation of the tenths of a millimeter. The *estimation of tenths* is very important in all physical work. The student must not only understand it, but also be able to put it in practice. Suppose Fig. 1 to represent part of your scale, and the position of dot B in the third measurement. The scale mark 30 is 30 cm. The smaller divisions which are not numbered are tenths of a centimeter; that is, millimeters. As the dot does not come exactly opposite to the third millimeter, we must estimate the tenths of a millimeter, and thus get the reading 30.29 cm. If the millimeter is taken as the unit, the reading will be 302.9 mm.

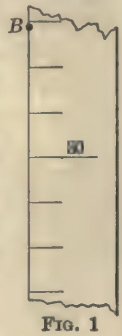


FIG. 1

2. Measure the same distance, using inches instead of centimeters. Change the distance thus obtained to centimeters and compare with the result of measurement No. 1.

3. Measure the length, in millimeters, of a new lead pencil before it has been sharpened. Measure its diameter, also in millimeters; call the length L and the diameter D, and compute its volume from the formula

$$V = \text{area of end} \times L.$$

But area of end $= \dfrac{\pi D^2}{4} = \dfrac{3.1416 \times D^2}{4}$; hence $V = \dfrac{3.1416 \times D^2 \times L}{4}$.

The character π is a Greek letter called *pi*, which represents the ratio of the circumference to the diameter of any circle. Its numerical value is approximately 3.1416.

Reduce the volume thus found to cubic centimeters.

The Micrometer Caliper. — An accurate instrument for the measurement of the diameters of small cylinders and spheres is the *micrometer caliper* or *sheet metal gauge.* This consists of a U-shaped piece of brass or steel, *A*, through one arm of which is threaded a screw, *B*, which is turned by the milled head *C*. On the inner metal sleeve extending from *E* to the right, there is a longitudinal scale, and on the end of the outer sleeve *D* there is a circular scale. When the end of the screw *B* touches the flat face of *K*, both zeros coincide; when any body, as *H*, is put between *K* and the end of *B*, — which is screwed in until it just touches *H*, — the diameter is measured by reading the two scales *E* and *D*.

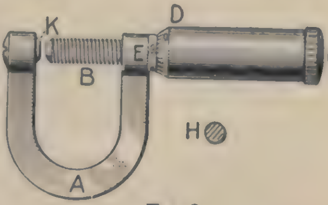


FIG. 2

4. Measure the diameters of five pieces of copper wire and compare the results with the diameters given in the wire table in the Appendix, and find the corresponding sizes by number.

5. Cut two triangles out of writing paper, making sure that the edges are straight. Call one side of each the base, as *AB* in Fig. 3, and call the opposite angle *C*. From *C* drop a perpendicular *CD* upon the base and compute the area by the formula, Area $= \frac{AB \times CD}{2}$. Do this for each triangle. Weigh each triangle carefully in a good balance and see how nearly the following proportion holds:

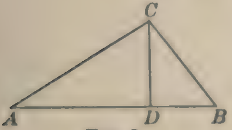


FIG. 3

$$\text{Mass of 1st} : \text{Mass of 2d} = \text{Area of 1st} : \text{Area of 2d}$$

Suppose you wish to find the area of an irregular-shaped piece of land; does this suggest a method for doing it?

6. Weigh out 500 g. of water — distilled if possible — and pour it into a graduate that reads to cubic centimeters. Is the volume 500 c.c.?

In reading with the graduate keep your eye on a level with the division read, and read from the bottom of the concave surface of the water, as in Fig. 4, line *AB*.

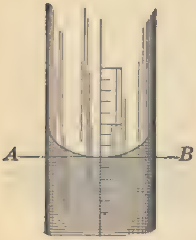


FIG. 4

7. Measure the diameter of a large steel bicycle ball with the micrometer caliper; compute its volume from the formula $V = \frac{4}{3}\pi r^3$; weigh. How does its weight compare with the weight of the same volume of water?

For the diameter take the average of a number of readings. Is the ball a sphere?

CHAPTER II

THE PROPERTIES OF MATTER

20. General and Specific Properties. — In considering the properties of matter a distinction should be made between those properties that belong to matter itself and those that belong to bodies only.

General properties are those found in all matter, such as *extension*, *division*, *impenetrability*, *porosity*, *elasticity*, *inertia.*

Specific properties are those found in certain kinds of matter only, such as *ductility*, *tenacity*, *hardness*, *malleability.*

Extension and *mass* are general properties and have been considered under the units used in measuring them.

21. Impenetrability. — Space that is occupied by one portion of matter cannot at the same time be occupied by any other portion. This is a property of matter rather than of bodies.

EXPERIMENT 1. — Fill a graduate with water to a convenient height and read. Thrust the end of a glass rod into the water and read again. The difference in the readings gives the measure of the amount of liquid displaced by the glass rod, and hence the volume of the part of the rod immersed.

EXPERIMENT 2. — Into a glass tube half a meter long pour water until it is nearly half full, add the same quantity of alcohol, mark the position of the top, and invert. When the liquids are thoroughly mixed, again mark the top of the liquid, and it will be found to be considerably lower than before. Why?

EXPERIMENT 3. — Pour alcohol into a large test tube until it is nearly full, and mark the height of its upper surface. Find out how much loose cotton (absorbent cotton is best) can be thrust into the alcohol without raising its surface. What does this experiment show?

22. Porosity. — A body is said to be porous, or to have porosity, because the particles of matter of which it is composed do not fill the entire volume occupied by it. The pores in bodies vary in size from those that can be seen in a sponge or piece of charcoal, to those in stone or metal, which may be invisible even though a microscope of the highest power be used.

The fact that a blotter absorbs ink and that a drop of oil will pass into a fine-grained piece of polished marble depends upon the porosity of the blotter and the marble.

Is this property indicated by any of the foregoing experiments?

Experiment 4. — Fill one glass with large peas, a second with small shot, and a third with water. Pour shot upon the peas and shake down, being careful that the surface of the peas is not raised. When no more shot can be put in, pour in water until it comes to the top of the peas. How large a part of the contents of the three glasses is now in one? What property of matter does the experiment illustrate? Compare this result with that found in Experiment 2.

Experiment 5. — Fill one glass with fresh water and a second with water which has been boiled for some time and then allowed to cool. Set them in a window in the sunshine and after an hour notice that the inside of one glass is covered with small air bubbles. Which glass is it? Why?

23. Compressibility. — Whenever the volume of a body can be reduced by pressure, it is said to be *compressible*. This property depends upon porosity, and is a measure of it. Gases are very compressible, solids to a less degree, while liquids are almost incompressible.

By doubling the pressure upon a gas its volume is diminished one half, while doubling the pressure upon water diminishes its volume only $\frac{1}{20000}$.

24. Indestructibility. — While matter can be made to assume different forms as the result of physical changes, and while it can be combined with other matter, or broken up into different kinds of matter, through chemical forces, yet matter itself cannot be destroyed.

Experiment 6. — To each end of a piece of German silver wire No. 30, 2 or 3 cm. long, solder a piece of copper wire No. 24, about 10 cm. long. Wind the German silver around a piece of phosphorus and place it in a test tube. Fix the test tube, inverted with its mouth beneath the surface of water, in a small beaker, as shown in Fig. 5. Balance this upon one scale pan of a balance, then ignite the phosphorus by touching the ends of the copper wire, *A* and *B*, with conductors from the poles of a battery, and it will be found that, though the phosphorus has been destroyed by the combustion, there has been no change in the mass, and consequently no destruction of matter.

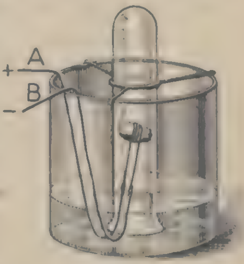


Fig. 5

25. Divisibility. — Bodies can be divided into smaller parts without changing the matter composing them. The property of divisibility has practically no limit. The finest crayon dust is made up of small bodies of chalk, as may be seen by examining it with a microscope.

Experiment 7. — Weigh out 1 mg. of fuchsine and dissolve it in 1 l. of water. Notice that though only one part in 1,000,000 is fuchsine, it colors every drop distinctly. Double the quantity of water and observe.

A drop of aniline copying ink can be used instead of the fuchsine.

26. Inertia is the tendency a body has to retain its condition of rest or motion. Whenever a body is at rest it can be put in motion only by some force outside of itself, and whenever a body is in motion the rate or direction of this motion can be changed only by the application of a force from without the body. This property is purely negative, but is one that has many important results.

Experiment 8. — Place a card upon a bottle with a small neck, and upon the card place a bicycle ball exactly over the mouth of the bottle. Snap the card with the finger, and it will be sent across the room, while the ball will drop into the bottle. Why?

Experiment 9. — Suspend a heavy weight by a cord, tie a fine thread around the middle of the weight, and pull the thread suddenly. It will break. Why? Tie on a new piece of the same thread and pull gently. The weight will be moved a little. If the pulls are repeated at the right times, the weight can be set swinging. Why?

Inertia is the cause of a great many accidents: the spilling of a liquid in a dish that is moved too quickly; the shock to a railway passenger when the air brakes are applied too suddenly; the fall resulting from jumping from a rapidly moving car, etc.

27. Elasticity is that property of matter by reason of which a body tends to resume its original shape or volume when either has been changed by any external force. Elasticity may be classified as follows (the corresponding external forces being given in parentheses):

(*a*) Elasticity of Compression (pressure).
(*b*) Elasticity of Traction (pulling).
(*c*) Elasticity of Flexion (bending).
(*d*) Elasticity of Torsion (twisting).

Experiment 10. — (*a*) Press a tennis ball between the hands; on removing the pressure it regains its shape. Why?

(*b*) Stretch a rubber band and slip it over a book. Why does it hold the book shut?

(*c*) Fasten one end of a piece of whalebone securely to a block. Bend the other end aside, and, on being released, it will vibrate back and forth and finally resume its original position. Why?

(*d*) Bore a quarter-inch hole in the middle of a block of wood a foot square, and drive in a wooden pin, letting it project a couple of inches. Slip one end of a rubber tube, two feet long, over this pin and tie it on with a cord. Fasten the other end of the tube to a support. Turn the block around with a twisting motion. It vibrates back and forth and finally comes to rest in its original position. Why?

Whenever a body does not return to its original shape or volume after being subjected to some external force, this force has exceeded the *elastic limit* of the body.

Some bodies require considerable force to change their form, but still have a high degree of elasticity. Ivory, celluloid, and marble are very elastic.

EXPERIMENT 11. — Make a paste by rubbing some lampblack into coal oil, and put a thin coating upon a flat slab of iron or stone. Place a large marble upon the slab. Notice how small a part of the marble touches the slab. Drop the marble from a height of 6 or 8 ft., and notice both the height to which it rebounds and the increased size of the contact between the marble and the slab. Explain.

28. Cohesion and Adhesion. — Cohesion is the force that holds together bodies of the same kind. It acts at very small distances and is diminished by an increase of temperature.

If the bodies thus held together are of different kinds, the force is called *adhesion.* There is no difference between the forces, and no especial need of two names. These forces are very great in solids, and serve to give them form and strength. In liquids cohesion is not strong enough to determine the form, except in very small quantities, when they take the form of drops. In gases cohesion is very slight. In many cases adhesion is greater than cohesion, as in the case of two boards glued together, or two pieces of china cemented to each other; if they are again broken, the break will be more likely to take place in the board or china than in the joint. Finely divided matter is often made into a solid body by compression, as in the making of emery wheels. If a piece of rubber gum is cut with a knife, the two pieces may be made to cohere perfectly by pressure.

Experiment 12. — Press together two pieces of window glass (plate glass is best) and hold them horizontally. Can they both be lifted by taking hold of the upper one? Put two or three drops of water between the plates and press them together. Try to lift the upper plate. Explain the results obtained.

Experiment 13. — With a sharp knife, cut off the bases from two conical bullets. Make the surfaces as nearly plane as possible. Press them together firmly with a twisting motion. Explain the result that is produced.

29. Tenacity is the property by virtue of which a body resists forces that tend to pull it apart. Tenacity is a direct result of cohesion, a tenacious substance being one that has great cohesion. *The tenacity of a substance varies directly as the breaking weight per unit area of cross section. E.g.* if two wires of different material, but of the same size, are tested, and it is found that 50 lb. are required to break one, and 100 lb. to break the other, then their tenacities are in the ratio of 1:2. If a wire 1 sq. mm. in cross section is broken by a pull of 50 lb., it will require a pull of 200 lb. to break a wire of the same material with a cross section of 4 sq. mm.

Experiment 14. — Cut a strip of Manilla paper 3 cm. wide and 25 cm. long. Make two loops by turning over the ends and pasting them down. Put a wooden rod through each loop, and to the ends of each rod tie the ends of a loop of strong cord. Fasten one loop to a support, and in the other put a wire hook, upon which hang a tin pail. Pour sand slowly into the pail until the paper strip breaks. Weigh the pail and its contents. What is this weight called? Make the same experiment with a strip of the same kind of paper 5 cm. wide, and observe whether the breaking weights in the two cases are in the ratio of 3:5.

The coefficient of tenacity is the quotient obtained by dividing the breaking weight by the area of cross section. This means that the coefficient of tenacity is the weight required to break the substance if the area of cross section is unity.

In bodies of the same material, tenacity varies with the form of the body. When the areas of cross section are equal, a tube has greater tenacity than a solid cylinder of the same material, and a wire with circular cross section has greater tenacity than one with a square cross section.

Tenacity diminishes with the length of time the load is carried, so that a wire may finally break with a load that it would carry safely at first. Tenacity also diminishes as the temperature increases.

30. Malleability is that property of matter by means of which it may be beaten or rolled into thin sheets. Brass can be rolled into sheets thinner than the paper of this book. The fact that tin foil and gold leaf can be made depends upon the malleability of the metals. Gold leaf is so thin that it is transparent.

31. Ductility is that property of matter by means of which it can be drawn into wire. Some metals possess great ductility. Platinum has been drawn into wire only 0.00003 of an inch thick. In order to do this, a small platinum wire was covered with silver, forming a compound cylinder, the silver surrounding the platinum much as the wood surrounds the graphite in a lead pencil. This cylinder was drawn into a very small wire, which had still a platinum center surrounded by silver; then the silver was dissolved by an acid which does not affect platinum, and the platinum was left as a wire of microscopic fineness. Glass threads have been drawn so fine that a mile would weigh only one third of a grain.

Experiment 15. — Take a piece of glass tubing about 10 cm. long by the ends and hold the middle in the flame of a Bunsen burner near the top. When it becomes cherry-red remove it from the flame and draw it out with a steady pull. Prove that it is a tube by blowing through it when one end is under the surface of water. Repeat the experiment, drawing the tube more rapidly. Can you get a tube so fine that you cannot blow through it?

32. Hardness is that property of matter which causes bodies to resist being scratched or worn by other bodies. It is a relative property, there being no such thing as an absolutely hard or soft body. Glass, which is harder than wax, is softer than the diamond. The diamond is the hardest of all natural substances, and diamond dust is used to cut other stones. Brittleness must not be mistaken for hardness. Steel, which is hard, is tough, while glass, which is also hard, is brittle.

33. Crystallization. — Some matter in the form of a solution has the property of forming crystals. Crystals may also be formed when a melted metal solidifies on cooling. Zinc shows this very plainly on account of the size of its crystals. In a piece cast in the form of a carpenter's square the crystals will form from the outside first and meet in lines in the center, as shown in Fig. 6. If *BC* is held firm and a force is applied at *A* in the direction indicated by the arrow, the casting will break along the line *CD*, since the crystals coming out from the sides of the mold meet along this line and make a *line of weakness*.

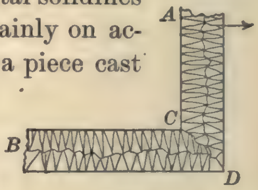


Fig. 6

Experiment 16. — Make a saturated solution of salt (see note on p. 29) and put in a beaker. Set this in a quiet place, and after a few hours you will find the surface of the liquid covered with little cubical crystals of salt. Let the solution stand for twenty-four hours and you will find groups of crystals floating on the surface. Carefully lift one of these out, invert it, and you will find a beautiful little pyramid formed of salt cubes. Why is the pyramid formed?

EXPERIMENT 17. — Make a saturated solution of salt and fill a teacup nearly full. Set the cup in a saucer and put in some quiet place. In a few days the salt crystals will creep over the edge of the cup and form a coating upon the outside and in the saucer. Vary the experiment by putting into the salt solution a little coloring matter.

EXPERIMENT 18. — Make a saturated solution of alum and hang in it a loop of cord so arranged that the two sides of the loop are at least an inch from each other. Put in a quiet place, and in a few days the loop will be covered with crystals of alum, which can be taken out and kept. Are the crystals of the same shape as the salt crystals?

NOTE. — By a *saturated solution* is meant one that will take up no more of the substance. When salt is put into water until, after thorough stirring, some of the salt is still not dissolved, the solution is said to be saturated. When such a solution begins to evaporate, crystals are formed. Raising the temperature of the solution usually causes more of the substance to be dissolved. When such a saturated solution is cooled, crystals are formed quickly.

PRACTICAL QUESTIONS AND PROBLEMS

1. Suppose you wish to pour a liquid into a bottle, using a funnel. Would you use a funnel that fits the mouth of the bottle air-tight? What is the reason for your answer?

2. What is the difference between the surface of writing paper and that of blotting paper?

3. Which is changed when a gas is compressed, the size of the molecules or the distance between them?

4. Suppose you mix chalk dust in water and filter it, and then dissolve salt in water and filter it. What is the difference between the liquids that pass through the filter? Why?

5. Why does a fly wheel help to steady the running of machinery?

6. Why does a carriage with pneumatic tires jar the rider less than one with solid tires?

7. What would be the effect if cohesion should cease to act in mortar?

8. Why is a stalk of wheat hollow?

9. Is wood more tenacious across the grain or lengthwise of it? Prove your answer by experiment.

10. What is meant by *tempering* a body? By *annealing* it?

LABORATORY WORK

1. Fill a graduate to any convenient height with water, and read. Suspend a stone, B (Fig. 7), in the water by a thread, and take a second reading. Pour out a little water, wipe the stone dry, and repeat. Take five sets of readings and tabulate the results. From the average result of these five readings compute the volume of the stone.

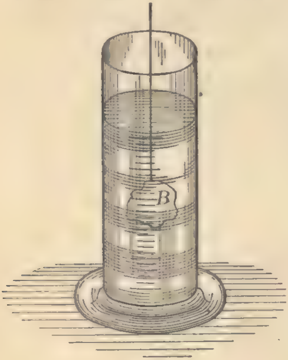


FIG. 7

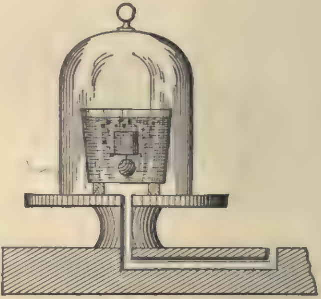


FIG. 8

2. Trim a piece of charcoal into some regular form. Measure it, compute its volume, and weigh it. Tie a weight to the charcoal by a thread, and put it into a beaker of water so that it is entirely covered. Place the beaker under the receiver of an air pump, as in Fig. 8, and exhaust the air. After you have taken as much air from the pores of the charcoal as you can, admit air into the receiver. Take out the charcoal, wipe it dry, and weigh again. From the difference between the two masses compute the volume of the pores in the charcoal. Find the real volume of the charcoal. How does it compare with the apparent volume?

3. Suspend a heavy weight from the end of a cord. Tie a piece of the same kind of cord to the weight so that it shall hang below it. Pull steadily on the lower cord; which one breaks? Give a sudden pull; which one breaks? Explain.

4. Sprinkle sand over a board one foot wide and a foot and a half long. Prepare a number of short wooden rods of different lengths and diameters, and set them on end on the board. Give the board a sharp blow on one end. Do all the rods fall? Why? Strike the board at the other end or at the side. Do the rods fall in the same direction as before? Why? The direction from which earthquake shocks come, and their comparative intensities, may be determined by such simple apparatus as this.

5. Make a rod *A* (Fig. 9) about 2 m. long and 1 cm. square. Screw two cleats, *B* and *C*, on a post in such a way that the rod *A* can be fastened at any point by the wedge *W*. Near the end of the rod make a cross, *D*. Arrange a metal sleeve to slide over the rod, and from it suspend a scale pan. Fasten a meter stick to a base, so that it will stand in a vertical position, as at *S*. Arrange a sliding finger *F*, so that the position of *D* can be read. Take a set of readings beginning with no load in the scale pan and increasing by regular amounts until the load is as great as you care to use. Tabulate your results and find the relation between the load carried by the rod and its deflection, the length being unchanged.

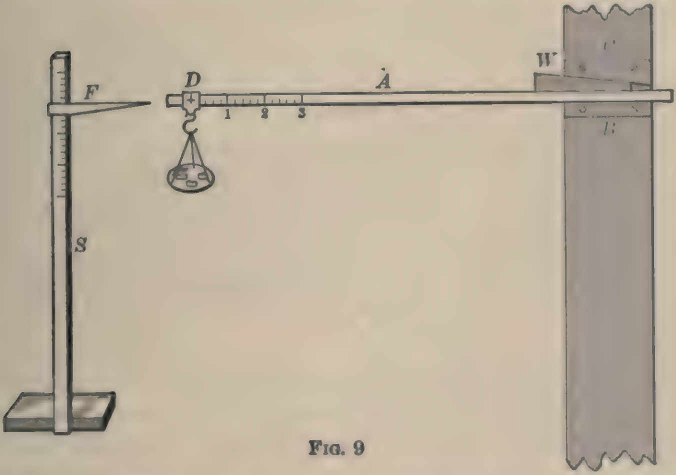


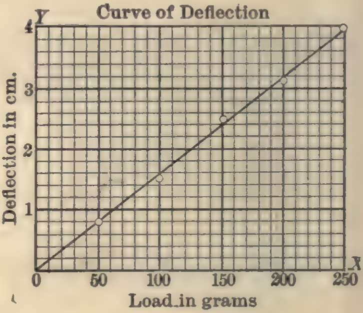
FIG. 9

By a second set of experiments find the relation between the deflection and the length, the load being unchanged.

34. The Graphical Method of Recording Results. — The clearest and most scientific method of showing the results of an experiment is what is known as the *graphical method* or *curve*.

To construct this record, two lines, called the axes, drawn at right angles to each other. The horizontal line is usually called the axis of X, and the vertical line the axis of Y, as in the diagram below, at the right. Lines are drawn at equal intervals parallel to these axes, every fifth line being made for convenience heavier than the others. Suppose the table on the left, just above, to be the tabulated result of the first part of No. 5, on the preceding page.

No.	Load	Def. in cm.
1.	50 g.	.8
2.	100 g.	1.5
3.	150 g.	2.5
4.	200 g.	3.1
5.	250 g.	4.0



Select the zero point at the lower left-hand corner of the paper. Let the loads be measured on the axis of X, and corresponding deflections on the axis of Y. Let each five spaces on X equal 50 g., and each five spaces on Y equal 1 cm. of deflection. The first point on the curve is found by following up the line marked 50 until .8 cm. is found, or until the horizontal line from the fourth division on the axis of Y intersects it: the intersection is marked by a dot, cross, or small circle. The other points are found in the same way, and then the curve is formed by joining all the points by a line.

The greater the number of points determined in the periment, the more nearly correct will the curve be. In this case the curve is practically a straight line. This means that the deflection is directly proportional to the load.

The *curve* also affords a ready means of finding points not determined by the experiment. Suppose that it is desired to know what the deflection would be for a load of 180 g. This can be found by going out to 180 on the axis of X, following the vertical line until it strikes the curve, and then following the horizontal line until the axis of Y is reached, where the scale reads a deflection of 2.88 cm. This process is called *interpolation*.

The student should make himself perfectly familiar with this graphical method, as its use is constantly increasing. Cross-section paper especially prepared for this kind of work can be obtained from stationers.

6. Cut from a quarter-inch dowel-pin rod — such as carpenters use — a piece 2 ft. long. Glue one end of this rod into a support so that it shall hang vertically, as in Fig. 10. Glue the lower end of the rod into a hole in the center of a wooden disk a foot in diameter. Drive a wire nail into the edge of the disk and tie a cord to it. Attach a spring balance to this cord and — pulling so that the cord shall always be tangent to the disk — note the relation between the pull and the angle through which the disk is turned. State this relation in the form of a law.

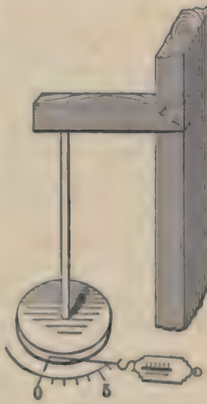


Fig. 10

7. Take another dowel-pin rod full length, 3 ft. for example. Fix the upper end as in No. 6 and attach two disks, *A* near the lower end, and *B* midway between that and the support. Twist with a scale as before and note the relation between the scale readings and the distances of *A* and *B* from the support when the angles of torsion are equal.

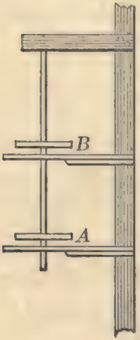


Fig. 11

8. Make a spiral spring by winding a coil of No. 18 spring brass wire tightly around a quarter-inch dowel-pin rod. A six-inch coil will be long enough. Bend in the ends of the wire so that they are in the axis of the coil, and make a loop in each. Suspend the spring from one end and read the position of a mark on the other, when there is no load attached, from a meter stick placed vertically behind the spring. Suspend from the lower end of the spring a small scale pan, and add weights enough to make the total load 100 g. Read again. Make the total load 200 g. and read. Add 100 g. each time and make several readings. Tabulate your results and make a curve showing the relation between the elongation of the spring and the load. Interpret the curve.

9. Thrust a wooden rod, 3 in. long, into each end of a rubber tube about 2 ft. long and tie securely. Place a dot of ink 2 in. from each end of the tube. Fasten one of the wooden rods to a support so that the tube will hang vertically, and from the other rod suspend a scale pan. Fix a meter stick in a vertical position behind the tube and read the positions of both dots. Add a load of 100 g. and read again. Take a number of readings, increasing the load 100 g. each time, and from the data obtained make a curve showing the relation between the load carried by the tube and its elongation.

10. In one end of a rubber tube, 2 ft. long, insert a glass tube and tie securely. Suspend this as shown in Fig. 12, and fasten in the other end of the rubber tube a hook made of a brass rod. Pour water into the tube until it stands at some level, as at *A*, keeping a record of the number of cubic centimeters poured in. Pour in an additional number of cubic centimeters of water

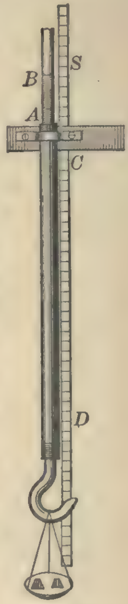


Fig. 12

until the level stands at *B*, and thus determine the value of a scale division of the scale *S* in cubic centimeters. Put two ink dots on the rubber tube at *C* and *D* and take readings of both. Take corresponding readings of the top of the water column. Repeat with added weights, as in No. 9, and make the curve showing the relation between the elongation and the volume of the tube.

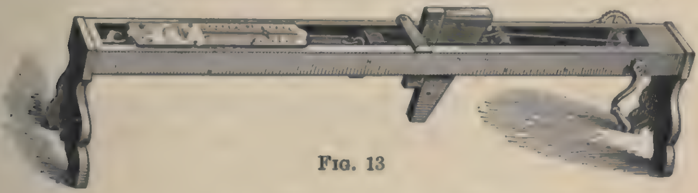


FIG. 13

11. A convenient testing machine for determining the breaking strength of wires is shown in Fig. 13. After fastening the wire in place, let one student bring a steadily increasing pressure to bear upon the handle while another reads the scale at the time of breaking. Make five trials each of spring brass wire, No. 27 and No. 30, and take the average of the results as the breaking strength. Measure the diameter of each, and calculate the breaking weight of spring brass per square centimeter of area of cross section.

12. Make a saturated solution of potassium bichromate. Pour a small quantity on a clear glass plate, and with a small stick work the liquid into the form of a flat, round mass. Set it in a quiet place over night, and in the morning observe the crystals with a reading glass or any small lens. Very beautiful slides can be made in this way for projection on the screen with the lantern or stereopticon.

CHAPTER III

THE MECHANICS OF SOLIDS

I. Motion, Velocity, and Force

35. Mechanics treats of the action of forces on bodies. It may be divided into two subjects: *statics* and *dynamics*. **Statics** treats of the laws governing forces when no motion is produced, and **Dynamics** or **Kinetics** treats of the laws governing forces by which motion is produced. If motion alone is considered without reference to the bodies moved or the forces producing the motion, the name **Kinematics** is applied.

36. Motion. — A body is said to have *motion* while it is passing continuously from one position to another. A body is at *rest* when its position remains unchanged. Rest and motion are, however, entirely relative. A body may be at rest in a railroad train, but in motion with respect to the earth. A body that is at rest with respect to the earth is in motion with respect to the sun.

The motion of a body is said to be *rectilinear* when it moves in a straight line. When a body moves in a path which constantly changes its direction, it is said to have a *curvilinear* motion, or to move in a *curve*. While it may not be difficult to imagine a body moving from one fixed point in space toward another without change of direction, in strict reality we know of no absolutely rectilinear motion of bodies. A stone falling from a balloon is moving toward the center of the earth, but this is itself moving about the sun, hence the motion of the stone must be in a curve. For all practical purposes, however, a body which moves without change of direction with reference to a room or the surface of the earth is said to move in a straight line.

If a body moves over equal spaces in equal times, its motion is said to be *uniform*. If the distances are not equal, its motion is *variable*.

37. Speed; Velocity. — Speed is the *rate of change of position* of a moving body, or its *rate of motion;* velocity is the speed in a definite direction. If the motion is uniform, the speed is the distance the body goes in a unit of time. If the motion is variable, the speed at any time is the distance it would move in a unit of time if it should continue to move at the same rate.

If the speed of a body is greater for each unit of time than it was for the preceding, it gives rise to *accelerated motion*. If this *acceleration* is the same for each unit of time, the motion is *uniformly accelerated*.

Motion is *retarded*, or negatively accelerated, when the speed is decreasing instead of increasing, and if the retardation is uniform, the motion is *uniformly retarded*.

Average or *mean speed* is the speed with which a body would need to move uniformly to pass over a certain space in a given time, though the actual speeds may be made up of a great many rates.

38. Space Passed Over. — The space passed over by a moving body depends upon two elements, speed and time. A train moving with an average speed of 20 mi. per hour moves 60 mi. in 3 hr. This relation may be expressed by the equation

$$\text{Space passed over} = \text{Average speed} \times \text{Time},$$

or, writing S for space passed over, v for average speed, and t for time, we have the formula

$$S = vt. \tag{1}$$

39. Acceleration. — When the motion of a body is uniformly accelerated, the rate of change in its speed or velocity is called its *acceleration*. If the body moves 5 ft. in one second, 7 ft. in the next, and 9 in the next, its acceleration is 2 ft. per second per second.

Suppose a body to move in a certain direction from a condition of rest with a constant acceleration a. At the end of t seconds its velocity per second will be represented by the equation

$$\text{Velocity} = \text{Acceleration} \times \text{Time},$$

or,
$$v = at. \tag{2}$$

On the above supposition, the average or mean velocity for t seconds will be $\frac{at}{2}$, and the entire space passed over will be

$$S = \frac{at}{2} \times t = \tfrac{1}{2}\, at^2. \tag{3}$$

By combining equations (2) and (3) we can derive the equation

$$S = \frac{v^2}{2\,a}, \tag{4}$$

from which
$$v = \sqrt{2\,aS}. \tag{5}$$

If in equation (3) the time is made 1 sec., the equation becomes $S = \frac{1}{2}\,a$, which shows that when a body starts from a condition of rest, and moves with a constant acceleration, the acceleration is twice the space passed over in the first second.

The space passed over during any second (the last of t seconds) may be found by subtracting from the distance passed over in t seconds the distance passed over in a time one second less. The space passed over in t seconds being (equation 3) $S = \frac{1}{2}at^2$, the space passed over in $(t-1)$ seconds will be $S' = \frac{1}{2}a(t-1)^2$. Hence the difference will be

$$s = S - S' = \tfrac{1}{2}at^2 - \tfrac{1}{2}a(t-1)^2 = \tfrac{1}{2}a(2t-1). \qquad (6)$$

40. Momentum. — The product of the mass of a body by its velocity is called its *momentum*, or quantity of motion. In the C. G. S. (centimeter-gram-second) system the unit of momentum is the *bole*, *i.e.* the momentum of 1 g. of matter moving with a velocity of 1 cm. per second. The expression

$$b = Mv \qquad (7)$$

is its formula in this system. There is no name for the unit in the F. P. S. (English or foot-pound-second) system, but the unit would practically be the momentum of 1 lb. moving at the rate of 1 ft. per second. A ferry-boat moving slowly has great momentum, as is shown when it strikes the side of the dock. Why?

41. Newton's Laws of Motion. — As a result of his investigation in this branch of physics, Sir Isaac Newton formulated the following laws:

I. *Every body tends to persevere in its state of rest or of uniform motion in a straight line, unless it is acted on by an impressed force.*

II. *Change of momentum is proportional to the impressed force, and takes place in the direction of the straight line in which the force acts.*

III. *To every action there is always an equal and contrary reaction.*

42. Newton's First Law. — If a body is left in a certain place, and after an interval it is not found there, we understand at once that it has been removed, that some force has been brought to bear upon it. If, however, a body is in motion, we cannot prove by actual experiment that it tends to go on in the same straight line, as the law states, because it is not possible to remove all resistances to a moving body, and these resistances are forces. But if the resistances are made as little as possible, the motion continues much longer. If a ball is rolled first on the ground, then on a floor, and then on smooth ice, with the same force each time, the effect of the reduced resistance is each time shown in the increased distance to which the ball rolls.

43. Newton's Second Law. — This law means that any force acting upon a body produces its own effect, whether acting alone or in conjunction with other forces. It also gives us the basis for the measurement of forces.

44. Force has already been defined as that which tends to produce, to change, or to destroy the motion of a body, that is, to change its momentum. From Newton's Second Law it is seen that the measurement of a force consists in determining the rate of this change. Since both the mass and the acceleration must be taken into account to determine this, the equation for a force is

$$F = Ma. \tag{8}$$

In the measurement of forces two units are used: the *absolute unit* and the *gravity unit.*

45. The Absolute Unit. — If a force acting upon a unit of mass gives to it an acceleration of 1 unit, then the force is the *absolute unit of force.* This unit in the C. G. S. system is the *dyne*, a force that, acting upon 1 g., will give to it an acceleration of 1 cm. per second per second. Since the dyne is a very small unit, it is sometimes convenient, in order to avoid the use of larger numbers, to use the *megadyne* (= 1 million dynes). In the F. P. S. system the unit is the *poundal*, which is the force that on being applied to 1 lb. of matter will give to it an acceleration of 1 ft. per second per second.

46. The Gravity Unit. — A force may also be measured by comparing it with the weight of a standard mass. Since gravity, acting upon a pound of matter for 1 sec., at New York, will give to it a velocity of very nearly 32.16 ft. per second, the pound, as a gravity unit, is there very nearly equal to 32.16 poundals. In the same place gravity, acting upon 1 g. of matter for 1 sec., causes it to acquire, when freely falling, a velocity of 980 cm. Hence the gram, as a gravity unit, equals 980 dynes at New York. As the force of gravity varies at different points on the earth's surface, the gravity unit is variable.

47. Graphical Representation of Forces. — If the motion of a body is that imparted by a single force, its path will be rectilinear, and may be represented by a straight line. The elements of a force are:

(*a*) Its point of application.
(*b*) Its direction.
(*c*) Its magnitude.

The force may be represented by a line beginning at the point of application, and extending in the direction in which the force acts to a distance which is a measure of its magnitude.

Both velocity and motion may be represented graphically. In fact, the graphic representation of a force may be considered the graphic representation of the motion produced by the force.

48. Composition of Forces. — When two forces, having the same point of application, act at the same time upon a movable particle, the path taken by the particle upon which they act will depend upon the direction and intensity of the forces. (Newton's Second Law.)

(*a*) *When the forces act in the same direction.* — Suppose two forces act upon a body, moving it toward the east, one with a velocity of 2 ft. per second, and the other with a velocity of 3 ft. Select a point *A* as the position of the body. Draw a line *Ax* (Fig. 14) to represent the direction in which the forces act. Take any convenient scale and lay off *AB* to represent 2 ft., and *AC* to represent 3 ft. Then will *B* and *C* represent the respective positions of the body at the end of 1 sec., if the forces acted separately. Since they act together, however, its position will be at *D*, 5 ft. from *A*. The forces *AB* and *AC* could be replaced by a single force *AD*, and this is called the *resultant*, while the forces themselves are called *components*.

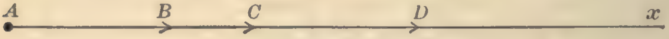


FIG. 14

The resultant of two forces acting in the same straight line, in the same direction, is the sum of the given forces.

(*b*) *When the forces act in opposite directions.* — Suppose the two forces to act, one toward the east and the other toward the west, as in Fig. 15. It is evident that the force *AB* will act against *AC*, and that the resultant will be *AD*, their difference.

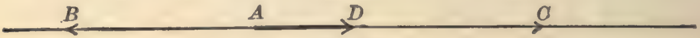


FIG. 15

The resultant of two forces acting in the same straight line, but in opposite directions, is the difference of the given forces and acts in the direction of the greater.

(*c*) *When the forces act at an angle to each other.* — THE PARALLELOGRAM OF FORCES. — (1) Suppose the force P to act at right angles to the force Q; then the body at A (Fig. 16) will move to the east a distance equal to AC, and to the south a distance equal to AB, and at the end of 1 sec. will be found at D ($ABCD$ being a parallelogram). The path of the body will be AD, the resultant R of the forces P and Q.

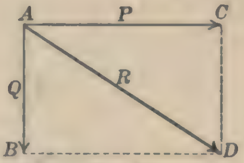


FIG. 16

(2) Suppose the force Q to act at an angle CAB to the force P (Fig. 17). Complete the parallelogram to determine the point D. Then will AD or R be the resultant required.

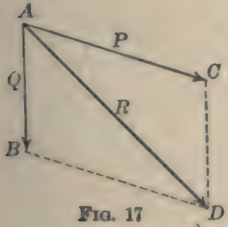


FIG. 17

The resultant of any two forces acting at an angle to each other may be found by completing the parallelogram upon the forces as sides and drawing the diagonal.

(*d*) *When there are more than two forces.* — The resultant of any number of forces can be found by a repetition of the parallelogram of forces. Suppose three forces, P, Q, and S (Fig. 18), to be acting on a body at A. Complete the parallelogram $ACDB$; then will AD or R' be the resultant of P and Q. Find the resultant R of S and R' by completing the parallelogram $ADHE$; then will AH or R be the resultant of P, Q, and S.

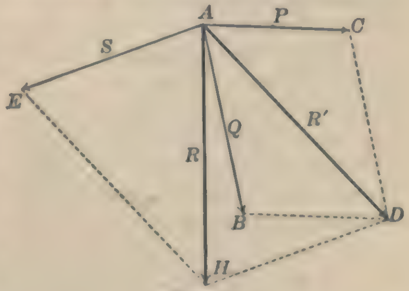


FIG. 18

49. Equilibrant. — The equilibrant of any number of forces is a force equal in magnitude, and opposite in direction, to their resultant. If the forces and their equilibrant act upon a body, the equilibrant will counteract the other forces, and the body will remain at rest. This condition is shown in Fig. 19, in which the equilibrant E and the forces P and Q keep the body A at rest.

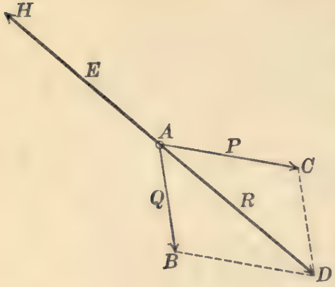


Fig. 19

50. Verification of the Parallelogram of Forces. — Experiment 19. — A and B (Fig. 20) are two hooks at the top of a blackboard. To these attach two spring balances, C and D. Hook these to the ends of a cord to which a second cord is tied at H. Suspend a weight W from this cord, and the point H will be kept in equilibrium by the three forces. The resultant of the pulls exerted by the scales C and D may be found by marking the position of H on the blackboard and the direction of the lines leading to C and D. Take Hc to represent the reading of the scale C, and Hd that of the scale D. Complete the parallelogram, and Hk, the resultant, will represent an amount equal to W, and will be vertical.

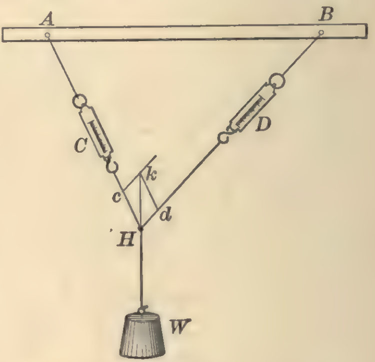


Fig. 20

51. Parallel Forces. — An important case is where two or more forces act in parallel directions upon a rigid body, but at different points of application.

Suppose two forces, P and Q (Fig. 21), are acting upon a rigid bar at the points A and B in parallel directions. Then will the resultant be equal to the sum of the forces in magnitude and parallel to them in direction, while its point of application will be at a point C, between A and B, such that $AC : BC = Q : P$. The equilibrant would also be applied at C, and is equal to R in magnitude and opposite to it in direction. If the forces P and Q are equal and act in opposite directions, the combination is called a *couple*, and produces rotation only, R being equal to zero.

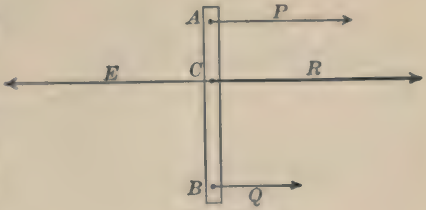


FIG. 21

EXPERIMENT 20. — The truth of the above proportion for determining the point of application may be verified by suspending from a meter stick two weights, P and Q, and supporting the stick and its load by a spring balance, as in Fig. 22. The weights can be supported from the meter stick by cords with loops passing over the stick, and the position of the scale can be found by slipping the loop to which it is attached along the stick until it balances in a horizontal direction. Before the proportion $P : Q = BC : AC$ is tested, a small weight should be suspended from the short end near A so that the stick will balance when the weights P and Q are removed. The scale will read not only the sum of P and Q, but the weight of the stick and small weight also.

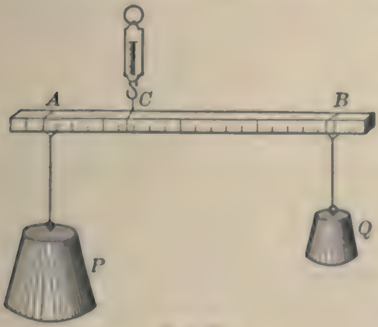


FIG. 22

The application of this principle is useful in determining the pressure upon the abutments of a bridge when a load is passing over it. If a load W (Fig. 23) — an engine, for example — passes over the bridge from A to B, the pressures upon A and B (in addition to the weight of the bridge) are constantly varying from the whole weight to zero, and *vice versa*, while the sum of the two pressures is always equal to the weight of the engine.

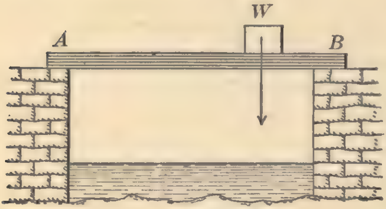


FIG. 23

52. Forces not lying in the Same Plane. — When three forces having the same point of application do not lie in the same plane, the resultant is the diagonal of the parallelopiped formed on these forces as edges. Suppose the three forces are P, Q, and S (Fig. 24). The resultant of P and Q is R' in the plane $ABEC$, while the diagonal AH is the resultant of R' and S in the plane $AEHD$, and is the required resultant.

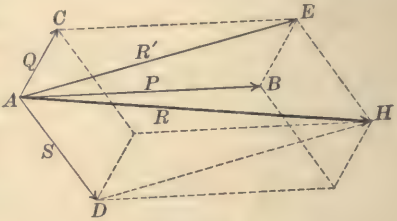


FIG. 24

53. Resolution of Forces. — In the composition of forces we have given the component forces to find the resultant, while in the resolution of forces the resultant is given and the components are to be found. There may be several cases of this problem.

(a) Given, the resultant and one of two components, to find the other component. Suppose the force P and one of its components Q are given, and it is required to find the other component. Complete the parallelogram on P as the diagonal and Q as one side. Then will C be the required component.

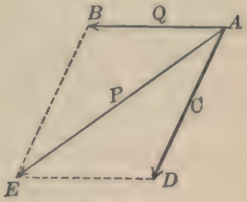


FIG. 25

(*b*) Given, the resultant and the direction of each of two components, to find the components.

(*c*) Given, the resultant and the magnitude of each of two components, to find the components.

Cases (*b*) and (*c*) are left for the student to solve.

54. Verification of Newton's Second Law. — When a body is dropped, it falls in a vertical line with a uniformly increasing velocity due to the constant force of gravity. If instead of being dropped it is struck a blow, it moves in a curved path, the resultant of the uniform motion due to the blow and the accelerated motion due to gravity. According to Newton's Second Law, the time of falling should be the same in both cases if the blow is given horizontally.

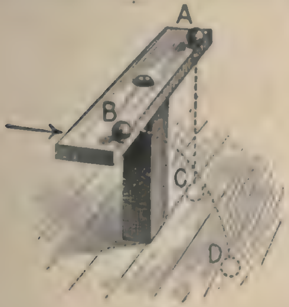


FIG. 26

EXPERIMENT 21. — Fasten a half-inch board, 18 in. long and 2 in. wide, to the top of a support by a round-headed screw passing through the middle. So arrange it that the board can turn easily in a horizontal plane. Cut two notches in the upper side of the board, and in each of these place a marble, as *A* and *B* (Fig. 26). Strike the board on the side opposite *B*, and the ball *A* will be dropped vertically, striking the floor at *C*, while the ball *B* will be projected horizontally. As soon as *B* leaves the support, its path will be the resultant of two motions: a uniform horizontal, and an accelerated vertical motion. The path will be the curved line *BD*. Do the balls strike the floor at the same time?

55. Newton's Third Law. — This law is only a statement of what we are familiar with, as *reaction*. If a cup is struck against the edge of a table, the table reacts against the cup and breaks it. If a swimmer attempts to dive from a spring board, he makes use of both the elasticity and the reaction of the board. In order to jump far a boy must stand on something solid, so that it shall react against the push of his muscles. If he should attempt a long jump when standing upon the seat of a swing, he would only succeed in setting the swing in motion and getting a fall.

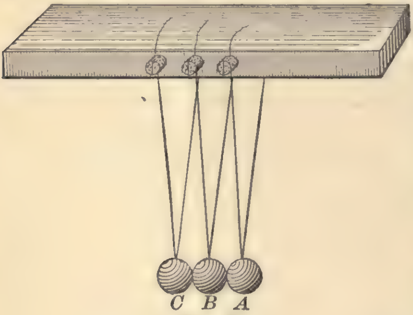


Fig. 27

Experiment 22. — Suspend three balls, *A*, *B*, and *C* (Fig. 27), by two cords each, from the opposite sides of a board about 3 in. wide. Pass the cords through split corks in the board, by means of which their length can be regulated and the balls brought into line. Draw the ball *A* to one side and then let it fall against *B*. The motion of *A* will be transmitted to *B*, from *B* to *C*, and as *C* is the last ball, it will be driven off a distance nearly as great as that to which *A* was raised. The experiment can be varied by adding more balls and then letting two or more fall together. Celluloid balls are easily obtained and are excellent for the experiment.

56. Reflected Motion. — If the ball *B* is firmly held when *A* strikes against it in Experiment 22, *A* will rebound. This is called *reflected motion*, and is caused by the reaction of the body against which *A* strikes. If the moving body is not elastic, the reaction of the body against which it strikes will flatten it, as, for example, when a ball of putty is dropped upon the floor. If the moving body is perfectly elastic, the direction of its rebound will be such that *the angle of reflection will equal the angle of incidence.* This is the *Law of Reflection*, and may be proved in reflected motion by the following experiment.

Experiment 23. — Place a strip of board on its edge upon a table resting against a wall. Roll a ball across the table along the line *AB* (Fig. 28) against the board. From *B*, where the ball strikes, draw *BD* perpendicular to the board. Then will the angle *CBD* — the angle of reflection — be equal to the angle *ABD* — the angle of incidence. (The path of the ball can be readily traced by dusting the table with crayon dust.)

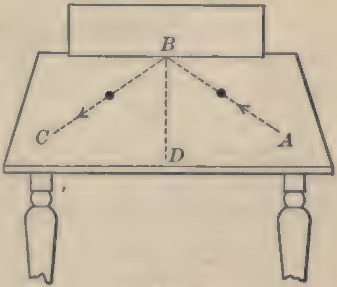


Fig. 28

57. Curvilinear Motion. — The path of a body whose motion is that imparted by a single impulsive force, is rectilinear. If its motion is due to two impulsive forces that have acted upon it, its path will still be rectilinear; but if the motion due to an impulsive force is combined with that due to a constant force, not acting in the same straight line, its path will be *curvilinear*. If a stone is tied to a cord and swung around, a curved path is the result. If the cord breaks, the stone goes off in a straight line — the tangent line *AB* (Fig. 29); but the cord prevents this and compels it to go in the curved path *ADE*.

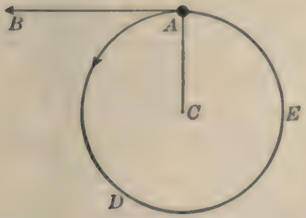


Fig. 29

58. Centrifugal Force. — The pull which the moving body produces upon the cord that compels it to move in the curved path is called *centrifugal force*, and is a result of the inertia of the body. The measure of this force is the *tension on the cord.* If part of the cord is replaced by a spring scale, its reading will be a measure of this force, which depends upon the mass of the body, its velocity, and the radius of the circle in which it moves. The formula is

$$\text{Centrifugal Force} = \frac{Mv^2}{r}; \qquad (9)$$

or,

$$F_c = \frac{Wv^2}{gr}. \qquad (10)$$

Equation 9 gives the result in absolute units, and Equation 10 in gravity units. (W = weight; g = velocity gained in 1 sec. by a freely falling body.)

Formula 9 can be obtained from a consideration of Fig. 30. Suppose a body of mass M to be moving around the circle whose center is O, with a uniform velocity v. The space AB, over which it passes in the time t, is $S = vt$. (Formula 1, p. 37 or 449.) Since the time t is taken as a very short time, the chord AB is practically equal to the arc AB, which is the real path. The distance the body is drawn away from AC toward O is

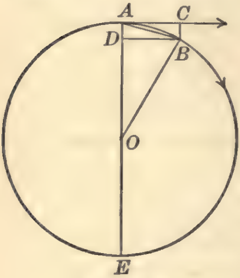


FIG. 30

$CB = AD = \frac{1}{2}at^2$. (Formula 3, p. 38)

Now, by geometry,* $\overline{AB}^2 = AD \times AE$,

or $v^2t^2 = \frac{1}{2}at^2 \times 2r$.

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* If B and E are connected by a straight line, AE will be the hypotenuse of a right-angled triangle, and BD a perpendicular dropped upon it from the vertex of the right angle.

Hence, $v^2 = ar$, and $a = \frac{v^2}{r}$.

But $F = Ma$. (Formula 8)

Hence, $F_c = \frac{Mv^2}{r}$.

59. Examples of Centrifugal Force. — There are many examples of this so-called centrifugal force. In every case in which the force that holds the body to the center is overcome, the body flies off in a direction tangent to the curve. The flying of mud from a carriage wheel, the bursting of a grindstone, the separation of the cream from the milk in a dairy separator, the action of the water in a centrifugal drying machine, are all results of this force.

It is on account of this tendency that a race course is banked to make the outside of the track the highest, and that on a curve the outer rail of a railroad track is higher than the inner rail.

Experiment 24. — Attach to a rotating machine a flattened glass globe, suspending it as in Fig. 31. Pour into the globe some mercury and colored water. Put the machine in motion, and the mercury will form a ring around the globe at its greatest diameter, as at *A*, while the water will form a second and smaller ring inside, as at *B*.

Experiment 25. — Replace the globe by the objects shown in Fig. 32: *A*, a small metal ring; *B*, a wooden curtain ring — large; *C*, a flat wooden disk suspended from the edge; *D*, a similar disk suspended from the middle of the side.

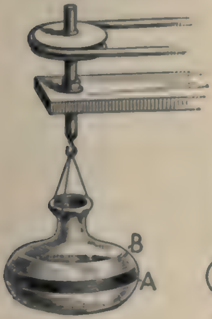

Fig. 31

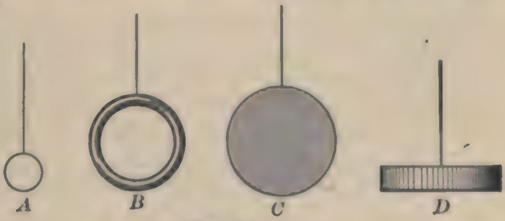

Fig. 32

PRACTICAL QUESTIONS AND PROBLEMS

1. Show by a figure that if the motion of a body is that imparted by two forces not acting in the same straight line, one force being constant and the other impulsive, its path will be a curve.

2. Give examples of five bodies in motion, and tell whether the path of each is rectilinear or curvilinear, with reference to the earth.

3. Suppose an express train to make a twenty-mile run in thirty minutes. Tell its probable average speed for the first half mile; for the tenth mile; for the last half mile.

4. A body moves from a condition of rest under the influence of a constant force which gives it an acceleration of 5 ft. per second per second. (*a*) How far will it move in 10 sec.? (*b*) How far in the seventh second? (*c*) What will be its speed at the end of 10 sec.?

5. Which has the greater momentum, a 100-lb. cannon ball moving with a velocity of 1026 ft. per second, or a freight car weighing 30,100 lb., moving at the rate of 15 mi. per hour?

6. How many dynes are required to give to a mass of 3 kg. a velocity of 20 cm. per second in 4 sec.?

7. A certain block of marble weighs 5 kg. at New York on a spring scale. To how many dynes is this equal?

8. Express in poundals a force of 10 lb.

9. How great a velocity will a force of 1500 poundals, acting for 3 sec., give to a mass of 8 lb.?

10. A sailor, on a ship that is sailing at the rate of 8 mi. per hour, climbs from the deck to a point on the rigging 50 ft. above in half a minute. Show by a figure the path he takes through the air, and compute its length.

11. Suppose three ropes are fastened to a ring, and a boy pulls on the first rope to the north with a pull of 50 lb.; another pulls on the second to the east with a pull of 70 lb.; and another pulls on the third rope in such a direction and with such a force as to keep the ring stationary. How much must the third boy pull, and in what direction? Solve this problem graphically.

12. A man rows a boat across a stream $\frac{3}{4}$ of a mile wide at the rate of 3 mi. per hour. The current carries him downstream at the rate of 2 mi. per hour. How long does it take him to cross the river?

13. Suppose the man in No. 12 wishes to proceed in a straight line to a point directly opposite. In what direction must he row, and how long will it take him?

14. A trolley car going east at the rate of 12 mi. per hour meets a north wind having a velocity of 25 ft. per second. In what direction does the wind seem to meet the car, and with what velocity?

15. Three forces act upon a movable point, one of 16 lb. tending to move it north, one of 24 lb. tending to move it west, and one of 56 lb. tending to move it southeast. Find the direction and intensity of the resultant. What must be the direction and intensity of a force that will keep the point from moving?

16. Where must the evener of a wagon be fastened to the pole that one horse may draw 1200 lb., and the other 800 lb., of every ton?

17. A weight of 300 lb. is suspended from a pole 10 ft. long resting on the shoulders of two men. Where must it be placed that one man may carry three fifths of the load?

18. An ocean steamer is going northeast at the rate of 400 miles per day (24 hours). How far north is she going per hour? How far east?

19. A force of 60 lb. is to be replaced by two components. One of them is a force of 40 lb. acting at an angle of 30° to the given force. At what angle does the other act, and what is its magnitude?

20. A body that weighs 16 lb. is moving with a speed of 30 ft. per second in a circle the radius of which is 8 ft. What pressure is required to keep it in its path?

LABORATORY WORK

1. Lay off a scale along the length of a light, stiff wooden rod, and suspend it from fixed supports by means of two spring balances

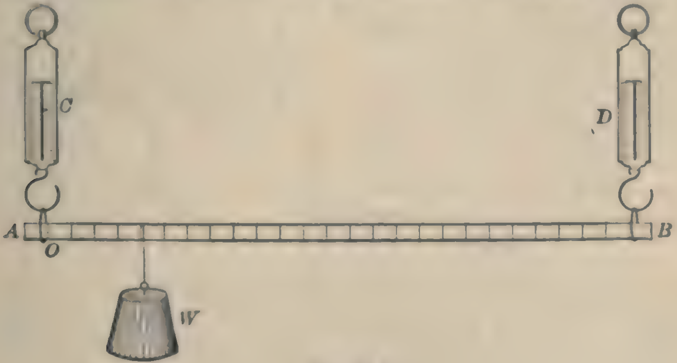

FIG. 33

C and *D* (Fig. 33). Suspend a weight *W* from the rod. Observe the readings of the scales. Take a series of readings, beginning with the weight suspended at *O* directly under the scale *C*, and tabulate the results in columns headed as follows:

Dist. from *O*	Reading of *C*	Reading of *D*

Make two curves on the same sheet of cross-section paper. Take distances of the weight *W* from *O* along the axis of *X*, and the readings of *C* and *D* along the axis of *Y*. These curves can both go on one sheet without interference, and a study of the curves will be instructive. To get good results, the scale readings must be corrected for the readings given by the rod alone before *W* is placed upon it.

2. In a board about 2 ft. square, put a row of wire nails an inch from the edge on two adjoining sides (Fig. 34). Place a wooden peg *A* in the middle of the board, and from this as a center describe a circle 10 in. in diameter, and divide the circumference into degrees. To a brass ring 1 in. in diameter attach three cords by three small rings as in Fig. 35. To the other ends of these cords attach the spring scales *B*, *C*, and *D*. Fasten *B* and *C* to any two nails, and draw *D* into such a position that the center of the ring *R* is the peg *A*. Read the scales and angles, and

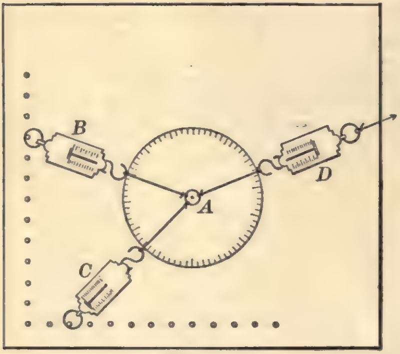

FIG. 34

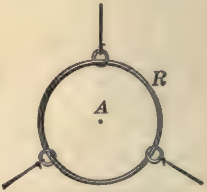

FIG. 35

from these readings construct the corresponding parallelogram of forces. Make the experiment with at least five different positions of the scales. The circle and its divisions can be made directly upon the board or upon heavy Manilla paper.

3. Make a circular whirling table like the one shown in Fig. 36, having across the diameter a brass wire *A* fixed in supports *B* and *C*. Upon the wire, place two pieces of brass rod, *D* and *E*, one weighing twice as much as the other, with a hole drilled through the middle of each large enough to admit the wire easily. Fasten these weights together with a rubber band as near the wire as possible. Draw a number of concentric circles at measured distances from the center, on a disk of Manilla paper, and tack to the table. Rotate the table at different speeds, and measure the respective distances of *D* and *E* by looking down from above and counting the circles. Can you verify Formula 9 (p. 50)? When two bodies are fastened together, about what point do they rotate?

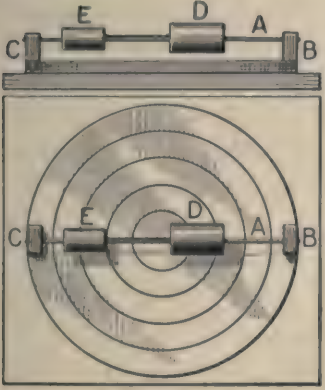

FIG. 36

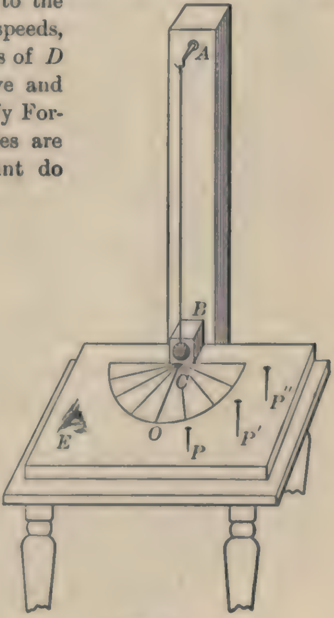

FIG. 37

4. At the middle of one side of a board 2 ft. square fasten a block *B* (Fig. 37). Place this board upon a table by the side of a post or window casing, and fix a screw hook into the post about 2 ft. above *B*. From this hook suspend a celluloid ball so that it will just touch the middle of the side of block B. From a point C, just below the center of the ball, as a center, describe a semicircle. From C draw the line CO perpendicular to the face of the block. Lay off equal distances from O on each side of the semicircle, and connect these points with C by heavy lines. On the prolongations of these lines from the right-hand divisions, set up pegs, P, P', etc. Fasten the ball to P' by a loop of thread. Place the eye at E, burn the thread with a match, and notice the direction in which the ball rebounds. Repeat at different positions. Is the angle of reflection equal to the angle of incidence?

II. WORK AND ENERGY

60. Work. — Whenever a force acts upon a body in such a way as to move it, or to modify its motion, *work* is said to be done. However great the force used, no work is done unless the body is moved. A man going upstairs, a boy playing ball, and a steam engine lifting coal from a mine, are all doing work.

61. Measurement of Work. — Since force and motion are required in work, the formula may be written

$$\text{Work} = FS. \qquad (11)$$

There are four *units of work*, as follows:

Absolute Units

I. *The erg* is the work done by the force of one dyne acting through a distance of one centimeter.

II. *The foot poundal* is the work done by a force of one poundal acting through a distance of one foot.

Gravity Units

III. *The kilogrammeter* is the work done in raising one kilogram one meter vertically against the force of gravity.

IV. *The foot pound* is the work done in raising one pound one foot vertically against the force of gravity.

The erg is the unit generally used in scientific work. 1 million ergs = 1 megalerg. The foot pound is the unit used in engineering work.

TABLE OF EQUIVALENTS AT NEW YORK

1 pound = 32.16 poundals.
1 foot pound = 32.16 foot poundals.
1 poundal = $\frac{1}{32.16}$ pound = $\frac{1}{2}$ oz. nearly.
1 gram = 980 dynes.
1 kilogrammeter = 98,000,000 ergs.

Referring to Formula 11, we see that if a man lifts a stone weighing 100 lb. $2\frac{1}{2}$ ft. high, the work done is $100 \times 2\frac{1}{2} = 250$ foot pounds, and that if an engine raises 12 kg. 20 m. high, the work done is $12 \times 20 = 240$ kilogrammeters.

62. Time is not an Element in Work. — Too great stress cannot be put upon the statement that the time employed in doing a certain amount of work has nothing whatever to do with the amount of work done. The dealer who pays a lump sum for the unloading of a boat load of coal, pays for that alone, and not for the time that may be consumed by the use of an imperfect hoisting machine.

63. Time: Rate of Work: Horse Power. — The work done in a given time, divided by the time, is the average rate of doing work, or *power*. A rate of 33,000 foot pounds per minute constitutes 1 *horse power*. An engine that can lift 19,800 lb. 100 ft. vertically in 1 hour can do $\frac{19800 \times 100}{60} = 33{,}000$ ft. lb. of work per minute. Hence

$$H.P. = \frac{\text{Foot pounds}}{33000 \times \text{minutes}}. \tag{12}$$

64. Energy. — If a ball weighing 20 lb. is raised to a shelf 10 ft. high, 200 foot pounds of work have been done upon it, and it is now in a position to do work, as can readily be seen by dropping it from the shelf. The winding of a watch gives to its coiled spring energy enough to run the watch for an entire day. So we may say that *energy is the capacity for doing work.*

65. Potential Energy. — The energy which a body has by virtue of its position is called *potential energy.* The measure of the potential energy of a body is the work that has been done upon it to give it its position, and we can write as its formula, $P.E. = FS$. As the work is usually employed in raising a weight, or working against gravity, the formula can be written

$$P.E. = Wh, \tag{13}$$

in which h is the vertical distance passed over by W, and the result is in units of work.

66. Kinetic Energy. — The energy that a body has by virtue of its velocity is called *kinetic energy.* The work that has been done on a body to give it a certain velocity is a measure of its kinetic energy. We have already learned that work = force × distance, and that force = mass × acceleration; hence we may write as an expression of kinetic energy,

$$K.E. = FS, = MaS.$$

But (Formula 4), $S = \frac{v^2}{2a}$; hence $K.E. = \frac{1}{2}Mv^2$, (14)

and since $M = \frac{W}{g}$, $K.E. = \frac{Wv^2}{2g}$. (15)

In this formula g is the acceleration of gravity, or 32.16 ft., so the formula may be written $K.E. = \frac{Wv^2}{64.32}$

when the mass is given in pounds and the result is required in foot pounds.

67. The Transformation of Energy. — The pendulum affords a ready means of showing that potential energy may be changed into kinetic, and *vice versa*. Let a ball A be suspended by a cord from a fixed point P (Fig. 38). The ball when at rest will take the position A, where, since it is at rest at its lowest point, it has neither potential nor kinetic energy. In order to move it to B, work must be done on it equivalent to raising it through the vertical distance DB. At B it has potential energy only, and if it is allowed to swing, it will move down the arc, losing potential energy and gaining kinetic, until it reaches A, when its energy will all be kinetic and sufficient to carry it up the other branch of the arc to the point C, a distance CE above the horizontal line, practically equal to DB; and here its energy is again all potential.

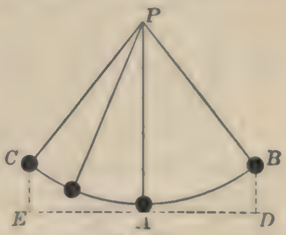

FIG. 38

The kinetic energy of the pendulum is employed in raising it against the force of gravity and restoring its potential energy. The case of a rifle ball striking against a stone wall is somewhat different. The motion of the ball is stopped and its kinetic energy is transformed chiefly into mechanical work and heat, for the ball itself is shattered, the wall is defaced, and if the velocity is very great, heat enough is produced to melt part of the ball.

The potential energy stored in coal may be transformed into heat energy by combustion, this into kinetic energy, if applied to a boiler and steam engine, and this into electrical energy, if the engine is used to turn a dynamo.

68. The Conservation of Energy. — When a ball is fired from a rifle, none of the energy that is developed by the combustion of the powder is lost, but it is all transformed into other forms of energy. Both the rifle and the ball are put in motion, producing kinetic energy; the air is thrown into vibration, producing sound; the ether is thrown into vibration, producing light; and to these results must be added the heat of the combustion. The sum of all these is equal to the potential energy of the powder, and there is no loss.

By extending the consideration to all kinds of transformation of energy, scientists have reached the conclusion that *energy can neither be created nor destroyed*, and hence that *the total amount of energy in the universe is constant.*

III. GRAVITATION AND GRAVITY

69. Law of Universal Gravitation. — Gravitation is the name given to the mutual attraction between different bodies of matter. The matter considered may be two books lying on a table, or two stars separated by millions of miles. The attraction is universal, and the *Law of Universal Gravitation* may be stated as follows: *Every particle of matter in the universe attracts every other particle with a force that varies directly as the product of the masses of the particles and inversely as the square of the distance between them.* This leads to the formula which is applicable to all mutual attractions, and which can be written

$$F_g = \frac{MM'}{d^2} a, \tag{16}$$

in which a is the unit of attraction; *i.e.* the attraction between two units of mass at a unit's distance.

Whenever two attractions are compared, they are usually of the same kind; hence we may write the proportion

$$F_g : F'_g = \frac{MM'}{d^2} : \frac{M''M'''}{(d')^2}.$$

The momenta given by mutual attraction to the two bodies between which the attraction acts, are equal. A man standing in a rowboat and pulling on a rope that is fast to a sloop moves the boat faster than the sloop, but only because its mass is much less. The momentum imparted to the sloop is equal to that given to the rowboat.

70. Gravity. — While the term *gravitation* is applied to the universal attraction existing between particles of matter, the more restricted term *gravity* is applied to the attraction that exists between the earth and bodies upon or near its surface. The law given above applies to it, and it acts along the straight line connecting the center of the earth and the center of mass of the body. This line is called a vertical line or sometimes a plumb line (from the Latin word *plumbum*, which means "lead"), as it is frequently determined by suspending a mass of lead, the *plumb bob*, at the end of a cord (Fig. 39).

FIG. 39

71. Weight. — The force of gravity acting on a body is measured by its *weight*, therefore weight may be defined as *the measure of the mutual attraction that exists between the earth and a body on or near its surface*, or, more briefly, *the measure of the earth's attraction for a body.*

Since the polar diameter of the earth is 26½ miles less than the equatorial, it is evident that the weight of a body will vary with the latitude as well as with the elevation above the sea level. The weight of a body carried from the equator toward either pole is increased by two causes: (1) the decrease in its distance from the center, and (2) the decrease in the centrifugal force of the earth's rotation; for since a body on the equator moves with a velocity of more than a thousand miles per hour, the centrifugal force is $\frac{1}{289}$ of the force of gravity, while at the poles it is zero. Should the earth rotate 17 times as fast as it now does, bodies at the equator would lose all their weight.

72. Weight above the Surface. — The maximum weight of a body is at the surface of the earth. If a body is removed above the sea level, as on the top of a mountain, or in a balloon, the distance d between it and the center of the earth is increased, and by reference to Formula 16 we see that its weight is diminished. The relation between weight at the surface and weight above the surface may be expressed by the proportion

$$W : w = d^2 : D^2, \qquad (17)$$

in which W is the weight at the surface; w, the weight above the surface; D, the distance from the center to the surface of the earth; and d, the distance of the body from the earth's center.

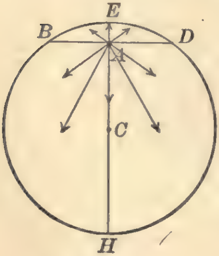

Fig. 40

73. Weight below the Surface. — If we consider the weight of a body at A (Fig. 40), below the earth's surface, we shall see that the attraction is now divided. The part of the earth above the line BD tends to draw the body in one direction, while the part below tends to draw it in another. The resultants of all these forces act in the line EH, the attraction of the part BDE being opposite to that of the part BDH, and the final resultant is the difference of these attractions. It can be proved that this difference is the same as the attraction of a globe whose center is at C, and whose radius is CA. In other words, the resultant attraction of the ring of matter outside of A is zero (Fig. 41). Hence we can write

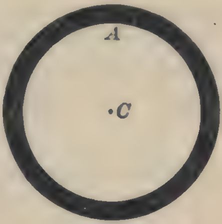

FIG. 41

$$W : w = D : d, \tag{18}$$

in which W and D have the same meaning as before, while w is the weight of the body below the surface, and d is its distance from the center of the earth.

74. Center of Gravity. — The attraction of gravity on any body tends to draw its particles toward one point, and hence, strictly speaking, the directions of these forces are not parallel. As the radius of the earth is very large, however, compared with the size of any object which is weighed, their divergence from parallel lines is, practically, not measurable. The point of application of all the parallel forces that make up the weight of a body is its *center of gravity*, *center of mass*, or *center of inertia*.

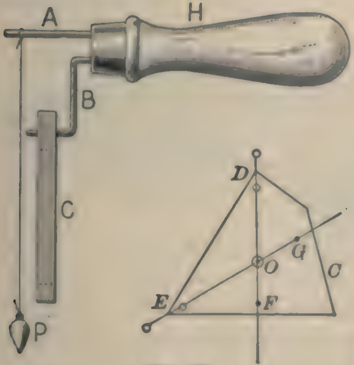

FIG. 42

EXPERIMENT 26. — Fit in a small wooden handle (or in a fixed support), two wires (Fig. 42): one, A, straight and the other, *B*, bent twice at right angles. In a piece of thin board *C* of any shape, bore holes *D* and *E* in two corners. Suspend the board by one of these holes *D* from the wire *B*, and from *A* suspend a plumb line. See that *D* is exactly halved by the plumb line when at rest, and mark a point *F* opposite the line. Suspend the board from the hole *E*, and mark the point *G*. Draw lines *DF* and *EG*, and their intersection *O* will determine the center of gravity. Test the accuracy of the work by making a hole at *O* and rotating on the end of *A*.

EXPERIMENT 27. — Find, in the same way, the centers of gravity of a triangle, a square, a rectangle, and a circle.

In the above cases the center of gravity is midway between the two surfaces at the point *O*. It would still be at *O*, if the thickness of the board were infinitely reduced; hence we may speak of the center of gravity of a surface. The center of gravity of any body may be found by suspending it successively from two points and finding the intersection of the lines of direction from those points of support to the center of the earth. The center of gravity is frequently outside the substance of the body, as in the case of a ring.

75. Equilibrium. — Pierce a disk of cardboard with two holes, one at the center, and the other near the edge.

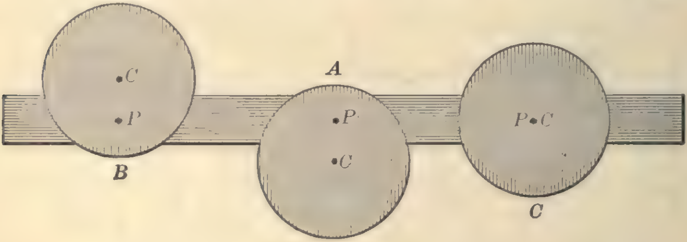

FIG. 43

Suspend it on a peg *P* (Fig. 43), from the hole near the edge, and it will take the position *A*, such that the center will lie in the vertical line below *P*. If the disk is moved, the center of gravity will be raised, and the disk will tend to return to its first position. This condition is that of *stable equilibrium.*

If the disk is placed in position *B*, and a slight push is given to it, the center of gravity will be lowered, and the disk will tend to go farther from its position. This is the condition of *unstable equilibrium.*

Place the disk in position *C*. Set it in motion, and the center of gravity neither rises nor falls, and the disk comes to rest in one position as well as another. This is the condition of *neutral equilibrium.*

76. Stability. — When a body is in a condition of stable equilibrium, a vertical line from the center of gravity will fall within the base of support, and in order that a body may have great stability the base must be large and the center of gravity low. A pyramid fulfills both these conditions. The center of gravity of a pyramid (Fig. 44, for example) is a point (C) on a line (GF) joining the vertex and the center of gravity of the base and at a distance from the base of $\frac{1}{4}$ the length of the line (that is, $CF = \frac{1}{4}\,GF$).

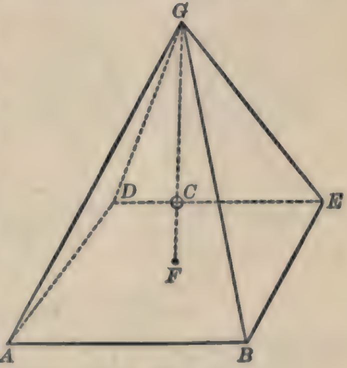

Fig. 44

77. Work Done in Overturning a Body. — The work that must be done to overturn a body is a measure of its stability. When a cylinder lies upon its side, the only work necessary to overturn it is to overcome the friction between it and the surface upon which it lies, since the center of gravity moves in a horizontal line. If, however, the body is a cube, the center of gravity is raised a distance *ab* every time it is turned over, and the work done is just the same as would be done in lifting the cube through the height *ab* (Fig. 45).

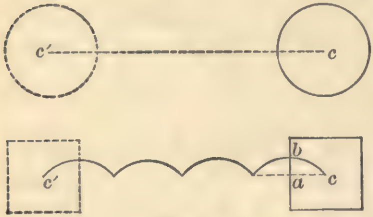

FIG. 45

A brick lying on a table upon its side has greater stability than one standing on end. The work necessary to overturn it in each case is expressed by the formula *Work* = *W* × *ab*. In both cases shown in Fig. 46 the highest position of the center of gravity is the same, but the original heights above the table are unequal, and so the product *W* × *ab* is greater in *A* than in *B*.

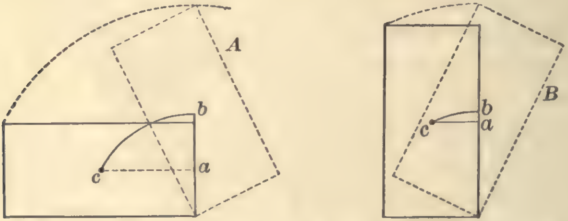

FIG. 46

EXPERIMENT 28. — Get a brass ball such as is used on the ends of curtain poles. Remove the screw and enlarge the hole so that it is large enough to pour in a little melted lead. Pour the lead in when the ball is fixed in position *A*. Put the ball in any other position, as *B*, and since a vertical line from the center of gravity *C* does not fall within the base *D*, the ball will roll and the center of gravity will fall until it reaches the lowest possible position, when a vertical line from *C* will fall within the base of support, and the ball will be in a condition of stable equilibrium.

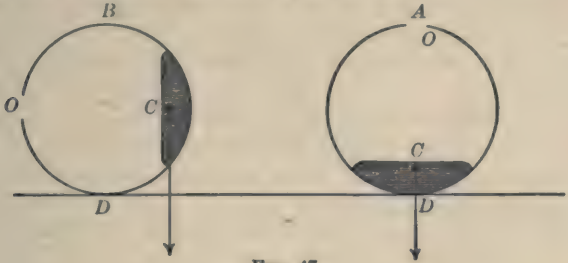

FIG. 47

The principle of this experiment is applied in making one kind of oil cans. The ordinary form is conical (Fig. 48, *A*), and if it is overturned the oil escapes. But when the base is made in the form of a hemisphere and loaded with a little lead in the bottom (*a*), the can will always right itself and the oil will be retained.

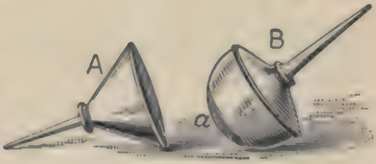

FIG. 48

PRACTICAL QUESTIONS AND PROBLEMS

1. How many ergs of work are done when a force of 126 dynes acts over a space of 3 m.?

2. Suppose a force of 16 poundals acts over a space of 121 ft. How much work is done?

3. Find the number of kilogrammeters of work done, when a force of 35 kg. acts over 143 m.

4. How much work is done when a force of 93 lb. acts over 114 ft.?

5. A stone 10 ft. long, 6 ft. wide, and 2.5 ft. thick, weighing 160 lb. per cubic foot, is lying on its side. How much work must be done to place it on its side on the top of a wall 12 ft. high?

6. A man weighing 160 lb. carries a hod and mortar weighing

75 lb. from the ground to a scaffold 24 ft. high, every 10 min. How much work does he do in 4 hr.?

7. How much work must be done to raise 120 long tons of coal from a mine 216 ft. deep? What must be the H.P. of an engine to do it in 4 hr. if the friction of the machinery increases the work 10 per cent?

8. A cylindrical well, 4 ft. in diameter and 72 ft. deep, has 16 ft. of water in it. What must be the H.P. of an engine to empty the well in 40 min., the weight of water being 62.5 lb. per cubic foot?

9. A standpipe 60 ft. high and 16 ft. in diameter is to be filled with water from a lake the surface of which is 8 ft. below the base of the standpipe. How long will it take a 10-H.P. engine to fill it?

10. A block of stone weighing 125 lb. is lying upon the ground. How much work does a man do who places it upon a post 3 ft. high? How much potential energy does it then have?

11. What is the kinetic energy of a 200-lb. cannon ball moving at the rate of 1164 ft. per second?

12. A ball weighing 25 kg. is rolling at the rate of 4 m. per second. What is its kinetic energy?

13. Which is greater, the attraction of the earth for a pound of iron, or the attraction of the pound of iron for the earth?

14. Suppose three balls weighing respectively 6, 10, and 18 lb. to be placed at the distances represented in Fig. 49. Suppose the attraction between *A* and *B* to be $7\frac{1}{2}$, what will the attraction be between *A* and *C*? Between *B* and *C*?

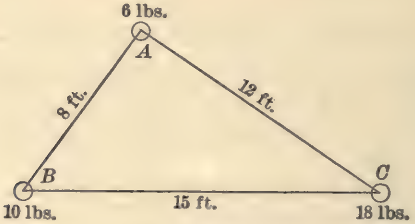

FIG. 49

15. What effect will it have upon the attraction between two bodies to increase the distance between them from 3 ft. to 9 ft.? To diminish it from 3 ft. to 1 ft.?

16. The weight of a body at the surface of the earth is 246 lb. What would be its weight if it were 1000 mi. above the earth's surface?

17. A wooden rod *R* to which there is attached a wire bent into the form of a semicircle and having a weight *W* attached at the other end, will, when placed on the end *B*, swing back and forth. Why?

18. A man standing with his back against a vertical wall cannot pick up anything from the floor in front of him without falling. Why?

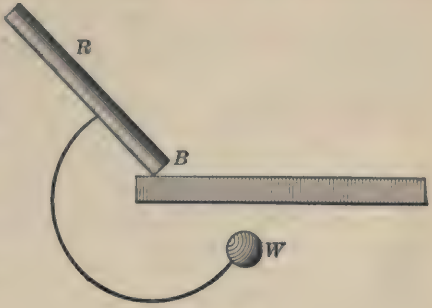

FIG. 50

19. A stone 4 ft. long, 3 ft. wide, and 2 ft. thick is lying on its side. The weight of the stone is 166 lb. per cubic foot. How much work must be done to turn it upon its edge? How much to set it on end?

20. A flagpole 100 ft. high is to be raised. It weighs 5¼ tons, and the center of gravity is 32 ft. from the base. How many foot pounds of work are required to raise it?

LABORATORY WORK

1. Prepare two triangular boards as nearly alike as possible and about 2 ft. long (Fig. 51). Find the center of gravity of each, and over it make a circle of black ink on the wood, as at *C*. In the base *DE* of one of the boards bore three half-inch holes and run them full of lead. Determine the center of gravity *L* of this board with its load, and make a circle of red ink over it. Make a like circle in the same place on the triangle *ABF*. Take each board by the vertex *K* or *F*, and toss it into the air with a whirling motion. What is the appearance of the circle *C* or *L* on each? Why?

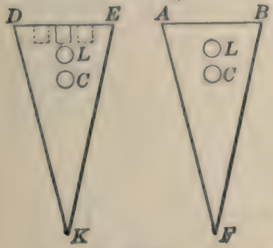

FIG. 51

2. Turn, on a lathe, a top like A (Fig. 52). Bore two holes, one in the hemisphere at B, and one in the handle at C. Pour melted lead into B, and cut a piece from a brass rod D, so that it will just fit into the hole C. Proportion the weights of the lead B and the brass rod D, so that when D is placed in C the top will stay as in the figure. Why will it not stay in that position when D is not in C?

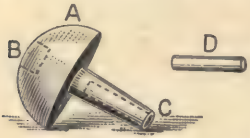

FIG. 52

3. Make two wooden cylinders, A and B, about an inch in diameter and 3 in. long. Drill a hole near the edge of A and parallel to its length. Fit tightly into it a piece of brass rod. Roll A and B both across the table and explain the difference in their motion. Show by a drawing the movement of the center of gravity in each case.

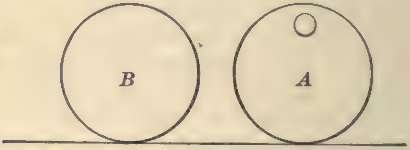

FIG. 53

4. The center of gravity of a number of bodies rigidly connected may be determined by considering the weight of each body as a parallel force applied at its center of gravity, and then finding the point of application of the resultant of these forces. Suppose three parallel forces, P, Q, and S, to be applied at three points, A, B, and C, rigidly connected, as in Fig. 54.

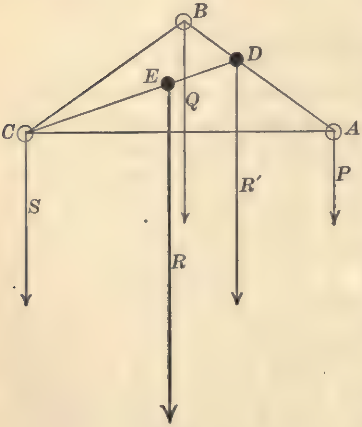

FIG. 54

The resultant R' of P and Q will equal $P + Q$, and its point of application will be at a point D, determined by the proportion

$$AD : DB = Q : P.$$

$$\therefore AD : AB = Q : P + Q,$$

or $$AD = \frac{AB \times Q}{P + Q}.$$

Now connect D with C, and the

three forces P, Q, and S are replaced by the two forces S and R'. Find in the same way the point of application E of their resultant, and this will be the center of gravity of the system.

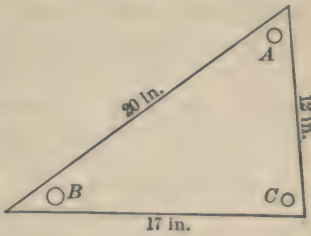

FIG. 55

To do this experimentally, select a board of uniform thickness, and cut from it a triangular piece, as in Fig. 55. Bore three holes of different sizes, A, B, and C, near the angles. Determine the center of gravity of the board by calculation. Fill the holes with lead plugs, weighing each one. Make a drawing of the board and the location of the plugs and determine the center of gravity by construction. Put a screw eye in the board at the point found. Does the board hang horizontally?

IV. FALLING BODIES

78. Accelerated Motion. — Whenever a body is moving under the influence of a constant force, the resulting motion is uniformly accelerated. If we let a represent the acceleration of such a body, and V its velocity at the beginning, we can write: —

$$\begin{aligned}\text{Velocity at the end of 1 sec.} &= V + a,\\ \text{Velocity at the end of 2 sec.} &= V + 2a,\\ \text{Velocity at the end of 3 sec.} &= V + 3a,\\ \text{Velocity at the end of } t \text{ sec.} &= V + ta,\end{aligned}$$

or $$v = V + at, \qquad (19)$$

a formula that differs from Formula 2 only in supposing an initial velocity.

The constant force with which we are most familiar is the force of gravity; hence, as an illustration of the effect of constant forces, we study the motion of a falling body.

79. A Freely Falling Body; Resistance of the Air. — A body that is moving under the influence of gravity alone is a *freely falling body.* This condition can be obtained only in a vacuum, as the air constantly offers a resistance to the passage of any body through it.

EXPERIMENT 29. — Trim a sheet of stiff paper about 5 × 7 in., a cork, and a small shot, till all are of the same weight. Drop them from the same height at exactly the same time, and notice when they strike the floor. Since they all have the same weight, the force tending to give them motion is the same, but as they present different amounts of surface to the air, the resistance of the air varies. This resistance acts in an opposite direction to gravity, and the resultant is the difference between them. If the sheet of paper is let fall when it is flat, it will slide down on the air in various directions, but if an inch of its edge is turned up at an angle, it will fall very steadily.

EXPERIMENT 30. — Drop two balls of the same size, one of brass and one of wood, from a height of 20 ft. or more. They reach the ground at practically the same time. Why?

Experiment 29 showed the effect of the resistance of the air. In order to avoid this, we make use of a long glass tube closed at one end and having a stopcock at the other. Put in this tube a small shot and a feather. On inverting the tube quickly the shot will be seen to fall much more rapidly than the feather. On repeating the experiment after exhausting the air from the tube by an air pump the two objects are seen to fall at the same time.

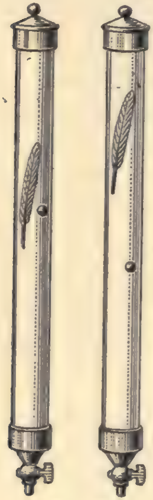

FIG. 56

80. Measuring the Velocity of Falling Bodies. — (*a*) *The Direct Method* consists of dropping a small ball of some heavy material from the top of a tower — like a shot tower — and determining by actual measurement where it strikes a support at the end of the first second, second second, etc. One of the difficulties connected with this method is the height of tower required, since for a fall of 3 sec. the tower would need to be about 145 ft. high.

(*b*) *Galileo's Method.* In all other methods the velocity of the falling body is reduced in some way. Galileo accomplished this by letting a ball roll down an inclined plane. If the length of the plane is made great in comparison with the height, the component of the weight that tends to roll the ball down the plane is only a small part of the weight itself. This is shown by comparing *ad* with *ab*, in Fig. 57 (see case *b*, p. 47). If the experiment is carefully made, the results will be such as are shown in Table A, since the resistance of the air is slight. Let *d* represent the space passed over in the first second, and it

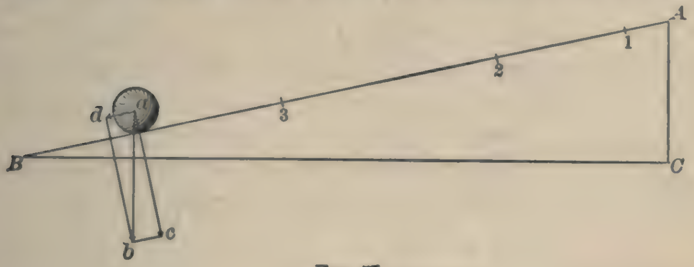

FIG. 57

TABLE A

Time in seconds	Velocity at end of second	Space passed over during the second	Whole space passed over
1	2d	d	d
2	4d	3d	4d
3	6d	5d	9d
4	8d	7d	16d

will be found that the entire distance passed over at the end of 2 sec. is 4 times as much, at the end of 3 sec. 9 times as much, etc. These observed results are shown in column 4 of Table A, from which it is a simple matter to obtain the values shown in column 3. Since the force is a constant one, the acceleration is constant, and is the difference between any two successive values in column 3, or $2d$. The acceleration $2d$ in turn gives the values in column 2.

If now we make a second table, replacing the acceleration $2d$ by a, we have Table B, from which we get Formulas 2, 3, and 6 for bodies moving under a constant force. By increasing the proportional height of the plane the velocity of the ball is increased, until, when the plane becomes vertical, the ball is no longer a rolling but a falling body. The relation between the acceleration of a ball rolling down an inclined plane and that of a falling body is expressed by the proportion $g : a = L : H$, in which g is the acceleration due to gravity, and L and H the length and height of the plane, respectively. From this $g = a \times \frac{L}{H}$.

TABLE B

t		s	S
1	a	$1 \times \frac{1}{2}a$	$1 \times \frac{1}{2}a$
2	$2a$	$3 \times \frac{1}{2}a$	$4 \times \frac{1}{2}a$
3	$3a$	$5 \times \frac{1}{2}a$	$9 \times \frac{1}{2}a$
4	$4a$	$7 \times \frac{1}{2}a$	$16 \times \frac{1}{2}a$
t	$v = at$	$s = \frac{1}{2}a(2t-1)$	$S = \frac{1}{2}at^2$

Replacing a in Formulas 2, 3, and 6 by g, we have the formulas for falling bodies:

$$v = gt, \tag{20}$$

$$s = \tfrac{1}{2}g(2t-1), \tag{21}$$

$$S = \tfrac{1}{2}gt^2. \tag{22}$$

The value of g for New York is 32.16 ft. or 980 cm. Making this substitution, these formulas may be written

$$v = 32.16\,t \qquad \text{or} \quad v = 980\,t,$$
$$s = 16.08\,(2\,t - 1) \text{ or } s = 490\,(2\,t - 1),$$
$$S = 16.08\,t^2 \qquad \text{or } S = 490\,t^2.$$

These formulas are very important, and should be familiar to every student.

(*c*) *Atwood's Method.* — In this method a piece of apparatus called Atwood's machine is used, in which the velocity is reduced by fastening two weights, which differ but little in amount, to the ends of a cord passing over a pulley. In practice, the friction is made as little as possible, by resting the axle upon friction wheels, and the cord is made of light silk. Let W and W' (Fig. 58) be two weights each of 240 g. Since they tend to turn the pulley P in opposite directions, the system will be in equilibrium. If now the weight W is raised until it rests upon a shelf S and a rider weighing 10 g. is slipped over the cord and placed upon W, the equilibrium will be destroyed, and the system will begin to move as soon as the shelf S, which is hinged, is dropped. Since the whole weight is 490 g., and since it is put in motion by the pull of a 10-g. weight, the velocity will be only $\frac{1}{49}$ of that of a freely falling body; hence a comparatively short distance is required for its fall during a number of seconds. The length of time that the force is acting to move the weight is regulated

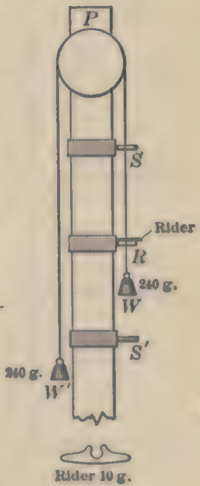

Fig. 58

by the position of the movable ring R, which is so arranged that the weight will pass through, but the rider be taken off. The times between the release of the weight, the taking off of the rider, and the striking of the weight upon the shelf S' are taken by means of a metronome, or of a pendulum beating seconds, and from these data a table similar to Table A is found.

81. Graphical Analysis of a Falling Body. — The motion of a falling body can be analyzed graphically as in Fig. 59. Draw a vertical line and take a certain distance AB, from the top of the line A, as the distance the body falls the first second, equal to $\frac{1}{2} g$. Measure from B twice this distance to represent the velocity gained during the first second. Make this a heavy line and extend a light line to C, a point $\frac{1}{2} g$ further on. Then will BC be made up of two parts, one of which is the velocity gained during the first second, and the other the distance it falls due to gravity acting on it for the second second. Points D, E, etc., may be found in a similar manner.

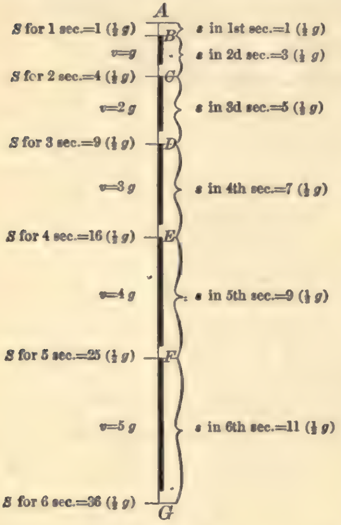

FIG. 59

82. Projectiles. — (*a*) *Bodies thrown Horizontally.* — The path of a projectile may be obtained by combining the uniform motion due to the impulsive force with the motion due to the force of gravity; and since gravity is a constant force, the body will generally move in a curved path. The path of a body thrown horizontally may be constructed graphically as follows (neglecting the resistance of the air). Take the axes as in Fig. 60. Let x represent horizontal motion and y vertical motion. Suppose the horizontal velocity is 50 ft. per second. Compute the values of S from the formula $S = \frac{1}{2} gt^2$, and determine the position of the projectile at the end of each second. A curve joining the positions will be the path required and will be found to be a *parabola*.

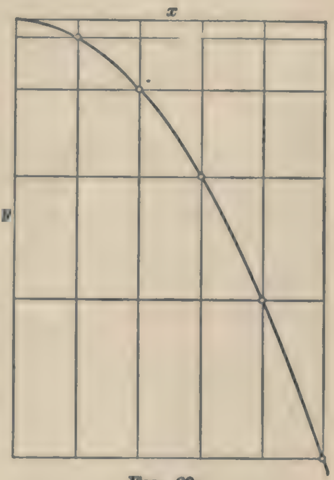

FIG. 60

(*b*) *Bodies thrown Vertically Upward.* — When a body is rising against the force of gravity, the loss in its velocity is the same as its gain in velocity when falling; *i.e.* 32.16 ft. per second, if we neglect the resistance of the air. Hence if a body is thrown vertically upward with a velocity of 64.32 ft., it rises for 2 sec., when its velocity is zero and it begins to fall. It then falls for 2 sec., and reaches the ground with its original velocity of 64.32 ft. The time during which a body will rise when thrown vertically upward may be expressed by the formula $t = \frac{v}{g}$.

(*c*) *Bodies thrown at an Angle.* — When a body is thrown at an angle, the velocity with which it is thrown in any direction may be considered a velocity of which the horizontal and vertical velocities are components. If in Fig. 61 *AB* represents the velocity with which a ball is thrown, the components *AC* and *AD* will represent the horizontal and vertical velocities respectively. The angle *BAC* is the *angle of elevation*, and the distance *AE* is the *range*. In the foregoing formulas no allowance has been made for the resistance of the air, but its effect upon the form of the path is shown in Fig. 61. Show what its effect would be in cases *a* and *b* of this section.

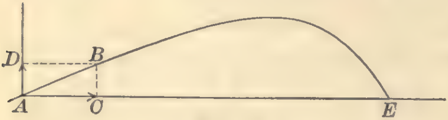

FIG. 61

V. THE PENDULUM

83. Simple Pendulum. — The ideal simple pendulum is one in which a heavy material particle is hung from a fixed point with a weightless cord. It is impossible to make such a pendulum, but we get nearly the required conditions by suspending a small ball by a light thread.

84. Motion of a Pendulum. — Whenever a pendulum, as *OA* (Fig. 62), is moved out of its position of rest to any other position, as *OB*, it will, on being released, go back to *A* and, owing to the kinetic energy developed by its fall, go on to the position *C*. This to and fro movement once over its path and back is called an *oscillation* or vibra-

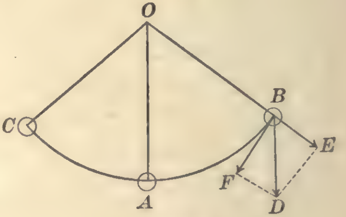

FIG. 62

tion; and the distance that A moves from its position of rest, — AB or AC, — is the *amplitude* of the oscillation. In order to find the force that causes the pendulum to move over this path, we must find two components of the force of gravity BD, one, BE, which produces a pressure on the point of suspension O, and the other, BF, which acts at a right angle to BE and is the force required. This force is given by the formula $BF = BD \sin AOB$.

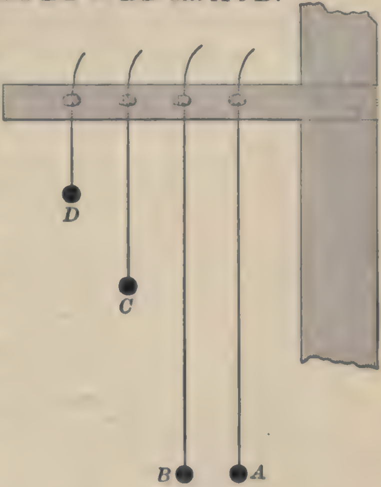

FIG. 63

EXPERIMENT 81. — From some form of support suspend four pendulums made by fastening lead balls to the ends of strong threads. Make two of them 1 m. long, one 50 cm., and the other 25 cm. Measure the distance from the point of suspension to the middle of each ball. Vibrate pendulums A and B. Do two pendulums of the same length vibrate in the same time? Vibrate A and B so that one swings about twice as far as the other. Do they still vibrate in the same time? Vibrate B and C. Does a pendulum half as long as another vibrate in half the time? Vibrate B and D. What is the relation between the time of vibration of one pendulum and that of another one fourth its length?

85. Laws of the Pendulum. — From an extension of the above experiment it is found that the relation between the time of vibration of a pendulum and its length may be expressed by the formula

$$t = 2\pi\sqrt{\frac{l}{g}}, \qquad (23)$$

in which t is the time of one complete vibration, and l is the length of the pendulum.

Another pendulum of length l' will vibrate in the same place in the time $t' = 2\pi\sqrt{\frac{l'}{g}}$, and we get the relation between these times by the proportion

$$t : t' = \sqrt{l} : \sqrt{l'}. \qquad (24)$$

86. The Seconds Pendulum is one which makes a half oscillation in one second. Its length varies with the value of g, and may be found for any place by substituting 2 for t and the value of g for that place in Formula 23 and solving for l.

$$2 = 2\pi\sqrt{\frac{l}{g}}. \quad \therefore \; l = \frac{g}{\pi^2}.$$

The value of g at Philadelphia is 980.18 cm. Hence the length of the seconds pendulum there is

$$l = \frac{980.18}{(3.1416)^2} = .993 \text{ m}.$$

87. The Compound Pendulum. — Any body suspended so as to vibrate in a vertical plane under the influence of gravity alone is a *compound pendulum.* The form usually used for practical purposes is that of a metallic bob suspended by a thin wire. The bob is made lens-shaped or thin on the edges, to offer less resistance to the air, and is arranged so that it can be raised or lowered on the wire to regulate the length of the pendulum.

88. Length of the Compound Pendulum. — EXPERIMENT 32. — From a suitable support (Fig. 64) suspend five pendulums; A, B, and C being of wood, and shaped as in the figure. Vibrate them in pairs. Do they vibrate in the same time? They are all of the same length as sticks; are they of the same length as pendulums? Vibrate each one with D, changing the length of the latter until they vibrate in the same time. Which is the shortest as a pendulum? Which is the longest? Now take the end of the pendulum *E*, — which is made by cutting gashes in shot and pinching them upon a thread, — draw it aside and let it swing. Do the shot form a straight line or a curve? Why?

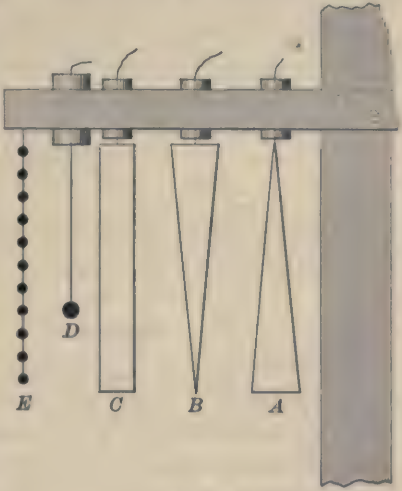

FIG. 64

89. Axis of Suspension. Center of Oscillation. — EXPERIMENT 33. — Cut a stick about 3 ft. long, 2 in. wide, and half an inch thick, and bore a quarter-inch hole through it near one end. Drive in a piece of dowel pin for an axis, and suspend it as in *A* (Fig. 65). Set it vibrating, and determine its length as a pendulum by comparison with the simple pendulum *D*. Mark off this length *BC* from *B*, and put a second pin through at *C*. Invert the pendulum and vibrate from *C*, and it will be found to vibrate in the same time as before.

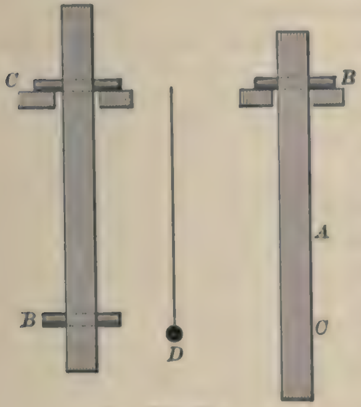

FIG. 65

The axis at *B* is the *axis of suspension*. The point *C* is the *center of oscillation*, and the experiment brings out the important fact that the axis of suspension and center of oscillation are *interchangeable*.

90. The Determination of *g*. — By making the axes in the shape of knife edges it is possible to measure the length of this form of pendulum (Kater's) very accurately. The distance between the knife edges being the length of a simple pendulum that vibrates in the same time, it can be substituted for l in Formula 23, from which

$$g = 4\frac{\pi^2 l}{t^2}.$$

Substituting also the time t determined by experiment, the value of g is determined.

91. Uses of the Pendulum. — The most common use of the pendulum is as a timekeeper. Since the vibrations are performed in equal intervals of time, or are isochronous, all that is needed is to make the to-and-fro motion of the pendulum regulate the rotary motion of the hands. This is done by the use of an escapement by means of which each complete vibration lets one tooth of a cogwheel escape, so that if the wheel has 20 teeth it will rotate once while the pendulum vibrates back and forth 20 times. In order that the times of vibration may be equal, the length must always be the same, and corrections must be made for the changes in length due to changes of temperature. In most pendulums this is done by moving the bob up or down by means of a nut running upon the wire support. It is sometimes done by the use of compensation pendulums, in some of which two different sets of metal rods are used so that the expansions shall oppose each other. In the mercurial pendulum, glass tubes filled with mercury are used for the bob. These are so arranged that the expansions and contractions of the mercury just counteract the effect of the contraction and expansion of the suspending rod.

PRACTICAL QUESTIONS AND PROBLEMS*

1. Write Formulas 20, 21, and 22, in the form of *laws.*

2. How far would a body fall from a state of rest in 6 sec.? How far would it fall in the fourth second? With what velocity would it strike at the end of the sixth second?

3. A stone is thrown horizontally from the top of a cliff, with a velocity of 80 ft. per second. It is seen to strike the ground in 4½ sec. How high is the cliff above the point where it struck? How far did it go vertically in the last second? What distance did it go horizontally before it struck? Draw its path on cross-section paper.

4. A rifle was fired horizontally from the top of a cliff 96.48 ft. high, on the shore of a lake. The bullet had a velocity of 731 ft. per second. How far from the foot of the cliff did it strike the water?

5. A ball weighing 3 lb. is dropped from a balloon 1 mi. high. What is its kinetic energy on striking the ground?

6. A stone is thrown over a church spire, and reaches the ground 5 sec. after it is thrown. How high is the spire?

7. A rifle ball is shot into the air with a velocity, the horizontal component of which is 1224 ft. per second, at such an angle that the highest part of its path is 100.5 ft. What is its range?

8. A projectile is thrown vertically into the air with a velocity of 144.72 ft. per second. How long does it rise? What is its greatest height?

9. Suppose a ball, rolling down a plank 12 ft. long, has an acceleration of 2 ft. How high is one end above the other?

10. A ball in rolling down an inclined plane passes over 2½ ft. in the first second. How far will it go in 4 sec.? What will be its velocity at the end of that time?

11. If the two weights of an Atwood's machine are 40 g. each, how much acceleration will a rider of 2 g. give?

12. Draw on the board the results of the motion in Problem 10, using the method of Fig. 59.

13. What must be the length of a pendulum to make a half oscillation in 1½ sec.?

14. What is the time of a half oscillation of a 4 ft. pendulum?

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* Except when otherwise stated, the value of g is to be considered 32.16 ft. or 980 cm. Problems are to be solved without considering the resistance of the air.

15. Would the time of vibration of a given pendulum increase or decrease, in going from the equator toward the south pole? Why?

16. State, in the form of a proportion, the relation between the numbers of vibrations and the lengths of two pendulums.

17. Do the same for numbers and times of vibration.

18. At Edinburgh the value of g is 981.54 cm. What is the length of the seconds pendulum there?

LABORATORY WORK

1. Fasten to each side of a straight-edged plank a strip of brass, in such a way that the edges project beyond the plank as in (*b*), Fig. 66.

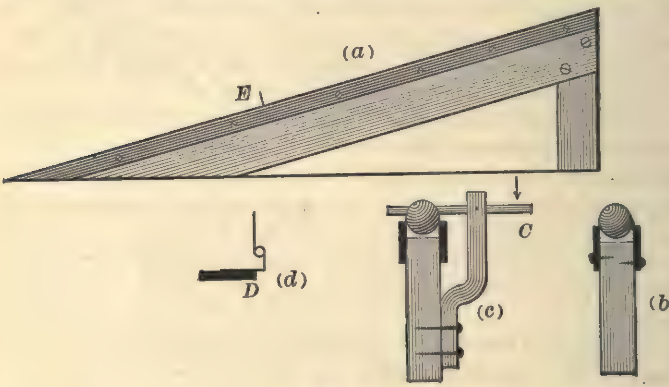

FIG. 66

The edges of these brass strips must be very straight and smooth. Mark off the edge of the plank between the brass strips into centimeters, placing the zero near the top. Place a celluloid or metal ball on the track near the top, keeping its front edge exactly at the zero mark by a device shown in (*c*). The ball can be released at any time by striking the lever at the point *C*. Make two or three little stops like the one shown at (*d*), each with two pieces of tin or thin brass hinged together. One piece, bent at a right angle, is then fastened to a lead base, and the stop is put in the trough between the rails of the track, and its position is read by seeing where the edge *D* comes. One of the stops is shown in place at *E*. Arrange a pendulum or a metronome to beat seconds audibly. Release the ball exactly at some beat.

and notice where it is at the next. Put one of the stops in place and repeat. Keep on repeating until the beat of the pendulum and the click of the ball striking the stop both come at the same time. The position of the stop gives the distance the ball has moved in the first second. Place a second stop farther down the plank, and arrange it so that the ball will strike it just at the second beat. The distance between the two stops will be the distance passed over in the second second.

If the stops are properly made, the hinged part will be knocked over by the ball, which will pass on without disturbing the heavy base. Make a set of experiments, and determine expressions for v, s, and S. Measure the height and length of the plane, and determine the value of g.

2. Make a board $ABCD$ (Fig. 67) about 3 ft. square. Fix at one corner a trough made by sawing a quarter of a circle from a board and extending it in a tangent line, as at F in the figure. Cut a groove in the inner edge of this, and holding a large marble at the upper end of the trough, let it fall. The ball leaves the trough in a horizontal direction with a velocity that depends upon the position from which it is dropped. Determine the position of the center of gravity G of the marble when it is on the point of leaving the trough. From G draw two lines, one horizontal, GD, and the other vertical, GH. Find by experiment some point, K, through which the marble passes when let fall from the top of the trough. From this point draw a vertical line KL, and lay off the distances LM, MN, etc., each equal to GL. From K draw also a horizontal line KR. Then lay off RO and OP respectively equal to 3 and 5 times GR; from O and P draw horizontal lines, and where they intersect vertical lines drawn from M and N respectively, two points in the marble's curved path will be located. Determine other points and draw in the curve by using a flexible whalebone for a ruler. Verify by dropping the marble as in the first place

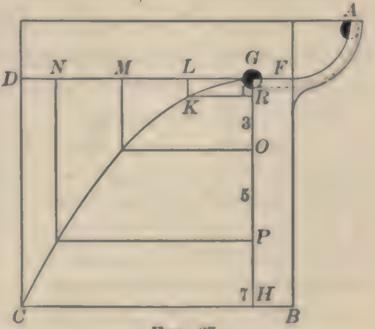

Fig. 67

Pin a piece of Manilla paper upon the board and determine other curves by dropping the marble from different heights.

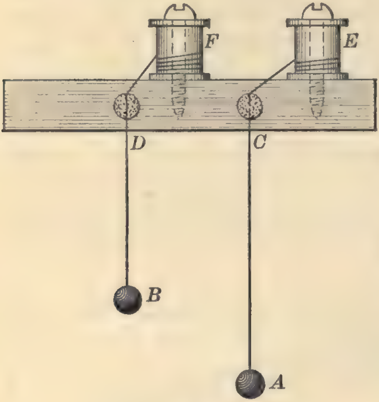

FIG. 68

3. Arrange two pendulums by suspending lead bullets at the ends of threads, as in Fig. 68. Fasten the other ends of the threads to spools E and F held in place by screws, and pass the threads through gashes cut with a knife in the ends of two corks, C and D, thrust in holes bored in the face of the support. Change the length of CA by turning E until it beats once per second. Measure the distance from the bottom of the cork C to the middle of A. Make B of such lengths that it will beat once in $\frac{4}{5}$, $\frac{2}{3}$, and $\frac{1}{2}$ sec. Measure the length of B in each case, and verify the law of time of vibration and length.

4. *To make and calibrate a pendulum for laboratory use.* — Get a piece of dry wood that will not warp, about $\frac{3}{4}$ in. thick, $1\frac{1}{2}$ in. wide, and 48 in. long. About an inch from one end bore a half-inch hole and put in a piece of dowel pin, A, about $2\frac{1}{2}$ in. long. Bore two small holes through the ends of this rod, and insert two wood screws, SS', sharpened to a point. On the top of two supports, BB', fix two plates of brass, PP', at such a distance apart that the screws will rest upon them. Bore two half-inch holes about 2 in. deep in the other end of

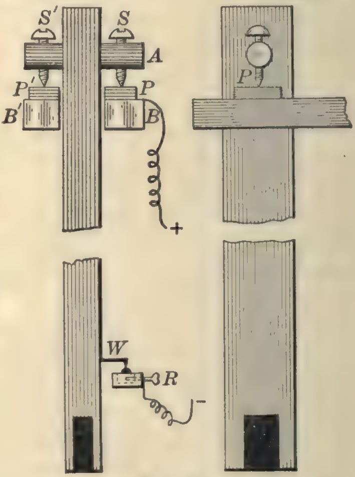

FIG. 69

the pendulum, and run them full of lead. At any convenient point near the lower end insert a short brass wire sharpened at one end and bent down at a right angle. Fix a block below this with a hole in it for holding mercury. Put an iron screw through the side of this block, and regulate the height of the mercury surface by it. Fasten one wire to this screw *R*, and carry another, attached to the pendulum, from the brass wire *W* to the screw *S*. Connect a wire to the plate *P*, upon which *S* rests, and carry it to a battery. Connect a telegraph sounder in series between the battery and the wire leading to the mercury cup. When these connections are made, the sounder will click every time the pendulum swings and the wire makes contact with the mercury. To determine the time of vibration, count the time for 100 vibrations and divide. This pendulum can be adjusted to beat seconds by attaching a sliding weight on the rod, and moving it to the proper position, or by varying the distance to which *S* and *S′* pass through *A*.

5. Bore ¼-inch holes in a meter stick, at intervals of 5 cm., along its entire length. Put dowel pins about 3 in. long in these holes. Provide suitable supports, and vibrate the stick as a pendulum from every pin. Observe all the phenomena, and make a curve showing the relation of the time of vibration to the distance of the point of suspension from the center.

6. Suspend a stick a meter long from one end by a very short string, and vibrate it. Find the length of a simple pendulum that vibrates in the same time. Paste a piece of paper on one side of the stick at a distance from the point of suspension equal to the length of the simple pendulum. Strike the pendulum at this point, then at a point above the mark, then at a point below, and notice the difference in effect upon the upper end of the pendulum. Explain. This point, which is the center of oscillation, is also the *center of percussion*.

VI. MACHINES

92. A Machine is a mechanical device used to apply force advantageously. Since it is impossible to make a machine that shall have no friction, the work that can be done by a machine is always less than the work that is put into it.

93. Efficiency. — The efficiency of a machine is the ratio of the work actually done by it, to the work that would be done if it had no friction. Various devices are adopted for making the friction as little as possible, one of the best being ball bearings such as are used in bicycles. If a machine could be made in which there were no friction, it would be a *perfect machine*. The efficiency of such a machine would be unity or 100%. The efficiency of a machine may be determined by finding experimentally the work that is done by the machine when a given force acts upon it, and dividing this result by the work that should be done by the same force according to the law of the machine. Efficiency is expressed as a per cent. An efficiency of 92% means that of every 100 parts of *total work*, there are 92 parts of *useful work*, and 8 parts lost by friction.

94. The General Law of Machines. — A law that is applicable to all machines is that the force multiplied by the distance through which it acts is equal to the resistance multiplied by the distance through which it is moved. This may be expressed in the form of the equation

$$Fd = RD. \qquad (25)$$

Each machine has its own law, which is generally more convenient than the above. But this law is general, and may be applied to any machine or combination of machines.

95. Simple Machines. — The many more or less complicated machines in common use may be reduced in principle to but six: the lever, pulley, wheel and axle, inclined plane, wedge, and screw. These are called the *mechanical powers* or *simple machines*. These six simple machines may be still further reduced to two, the lever and inclined plane, as it can easily be shown that the pulley and the wheel and axle are only modified levers, while the screw and wedge are modified inclined planes.

96. The Moment of a Force. — Suppose there are two forces, F and F', acting upon the bar AB, and tending to rotate it about the pivot C. It is evident that the tendency of each force to produce rotation depends not only upon the value of the force itself, but also upon its distance from the point C, about which it tends to turn the bar. Since both the force and its distance from C enter into this tendency to produce rotation, the effect may be expressed by their product. If the distance AC is d, and CB is d', the tendency to produce rotation exerted by F is proportional to Fd, and this is called the *moment of the force F*. So, too, the moment of the force $F' = F'd'$.

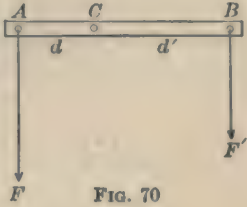

FIG. 70

If additional forces are applied at different points along the lever, equilibrium will be maintained when the sum of the moments producing clockwise rotation is equal to the sum of the moments producing counter-clockwise rotation. Since counter-clockwise rotation is measured by positive angles, it is sometimes called positive, and clockwise rotation negative. The point about which the rotation takes place, as C, is called the *center of moments*.

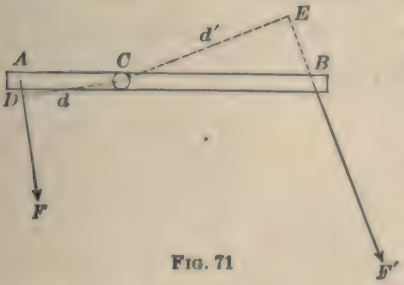

FIG. 71

If the forces F and F' do not act in a direction that is perpendicular to the bar AB, as in Fig. 71, then the distances d and d' will not be AC and CB, but CD and CE, which are the perpendiculars drawn from C to the directions of the forces.

The moment of a force, then, is measured by *the product of the force by the perpendicular distance from the center of moments to the direction of the force.*

97. The Lever is a rigid bar that is capable of movement about a fixed point called the *fulcrum.* There are three classes of levers, which are distinguished by the relative positions of the fulcrum and of the points of application of the applied force and the opposing force. The applied force may conveniently be called the power, the opposing force the weight or resistance.

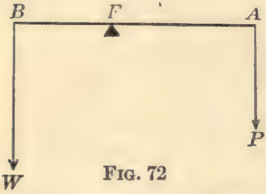

FIG. 72

(*a*) *Levers of the First Class.* — Figure 72 shows a lever of the first class (AB), in which the power is applied at one end, and the weight at the other, with the fulcrum between them.

(*b*) *Levers of the Second Class.* — In a lever of the second class the power is at one end and the fulcrum at the other, with the weight between them, as in Fig. 73.

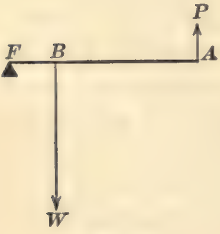

FIG. 73

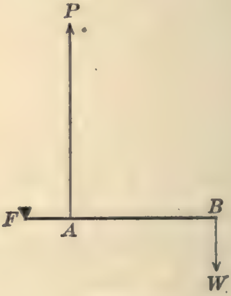

FIG. 74

(*c*) *Levers of the Third Class.* — The lever of the third class, as shown in Fig. 74, has the weight at one end and the fulcrum at the other, with the power between them.

98. The Law of Equilibrium of the Lever. — By applying the principle of moments to the lever, we can readily find an expression for the law. As F is fixed in every case, it is the center of moments, and when the lever is in equilibrium the moment of P equals the moment of W. Hence $P \times AF = W \times BF$. Writing this as a proportion, it will stand

$$P : W = BF : AF,$$

or Power : Weight = Weight arm : Power arm,

in which "arm" means the perpendicular from the fulcrum to the direction of the force. To make the formula universally applicable we must write Resistance in place of Weight, thus:

$$\text{Power} : \text{Resistance} = \text{Resistance arm} : \text{Power arm}. \qquad (26)$$

99. Static Laws. — The above laws of machines are *static laws*, and are applicable to conditions of rest only. If motion is to be given, the weight that can be moved or the resistance that can be overcome by a given power will depend upon the kind of machine and upon friction, *i.e.* upon its efficiency.

100. The Bent Lever. — When a hammer is used to draw a nail, it is a lever of the first class, though the fulcrum is not in a straight line joining the points of application of the power and the resistance. This constitutes a *bent lever*. The law of moments holds for it. For Formula 26 the "arms" are the dotted lines in the figure.

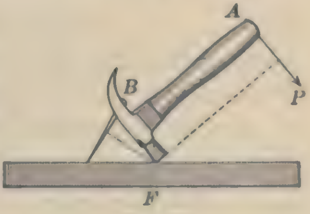

Fig. 75

101. The Common Balance is a lever of the first class with equal arms, hence in this case $P = W$. In order that the balance may be accurate, the parts of the beam on each side of the fulcrum must be of equal weights and lengths. In order that it may be sensitive the arms must be light, the friction must be little, and the knife-edge fulcrum must be very close to a line joining the knife edges of the scale pans, with the center of gravity of the arms just below it. If the arms of the beam are of equal weights, but of unequal lengths, it will still be possible to determine the true weight of the object to be weighed.

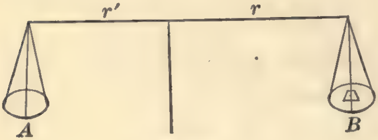

Fig. 76

In Fig. 76, suppose the body to be weighed first in one pan and then in the other. Call its true weight W, its apparent weight when placed in A, W', and when placed in B, W'', then from the principle of moments we have

$$Wr' = W'r,$$

and

$$Wr = W''r'.$$

$$\therefore W^2rr' = W' W''rr',$$

or

$$W^2 = W' W'',$$

and

$$W = \sqrt{W' W''}. \tag{27}$$

Hence, to find the true weight of a body with a balance of unequal arms, find its apparent weight in each scale pan, and take the square root of their product.

102. The Steelyard is a lever of the first class with unequal arms. By having one hook to which the article to be weighed is attached, and two, by either of which the steelyard may be supported, both sides of the bar are used, one for light and the other for heavy bodies.

103. The Compound Lever. — If the short arm of one lever is made to work upon the long arm of a second, the combination is called a *compound lever*. The mechanical advantage may be found by applying the general law of machines. The platform scale used for weighing hay or coal is an example of its application.

104. The Wheel and Axle is a modified lever of the first class if, as is usual, the power is applied at the circumference of the wheel, and the weight at the circumference of the axle. Then the power arm is the radius of the wheel, and the weight arm is the radius of the axle. In Fig. 77 the power is applied at A, the weight at B, the fulcrum is at C (the center of both wheel and axle), and the lever arms are R and r respectively.

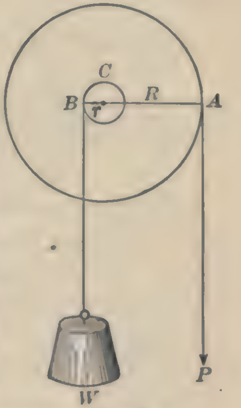

FIG. 77

105. Law of the Wheel and Axle. — Since the moment of the power must equal the moment of the weight whenever there is equilibrium, we may write, from Fig. 77,

$$PR = Wr.$$

$$\therefore W = \frac{PR}{r} = \frac{R}{r}P,$$

and

$$P = \frac{r}{R}W,$$

or

$$P : W = r : R. \tag{28}$$

This can be stated as follows: *A certain power applied to the wheel and axle can support a weight as many times greater than itself as the radius of the wheel is times greater than the radius of the axle.* The radii in Formula 28 can be replaced by either the circumferences or the diameters if it is more convenient.

The wheel and axle is used to raise water from a well, to hoist ore from a mine, as with the windlass, to move buildings, and to raise anchors, as with the capstan. In the capstan no wheel is used, but instead straight bars, called handspikes, are put into holes in the head of the capstan, and the power is applied to these (Fig. 78).

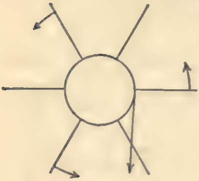

FIG. 78

106. Combinations of the Wheel and Axle, with the axle of one system working upon the wheel of another, are used, not only where great weights are to be lifted, but also where it is desired to make a great difference in speed between the movement of the power and of the resistance. In all such combinations the law may be stated thus: $P : W =$ the product of the radii of all the axles : the product of the radii of all the wheels.

NOTE. — Let the student modify and state the formulas of §§ 105, 106 as they would be altered if the *weight* is applied to the wheel and the *power* to the axle. A wheel and axle so used would be a modified lever of what class?

107. The Pulley. — The fixed pulley, like the wheel and axle, is a modified lever; but in this machine the power arm is always equal to the weight arm, so that there is no gain in using a single fixed pulley, except change in direction. This may be seen readily by reference to Fig. 79. The power is applied at one end of a

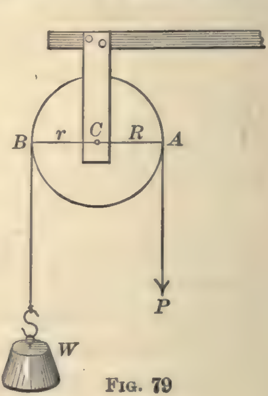

FIG. 79

rope that passes around the pulley in a groove cut in its edge, and is tangent at the points A and B. Apply the law of the lever, and the proportion will stand

$$P : W = r : R;$$

but

$$r = R.$$

$$\therefore P = W. \qquad (29)$$

108. The Movable Pulley, like the fixed, is a modified lever, but it is of the second class, the fulcrum being at B (Fig. 80), the weight (including the weight of the pulley) being applied at C with a lever arm $BC = R$, and the power at A with a lever arm $AB = D$. The formula for the single movable pulley is $P : W = R : D$, and since D is the diameter and R is the radius of the pulley, this becomes

$$P : W = 1 : 2$$

or

$$P = \tfrac{1}{2} W. \qquad (30)$$

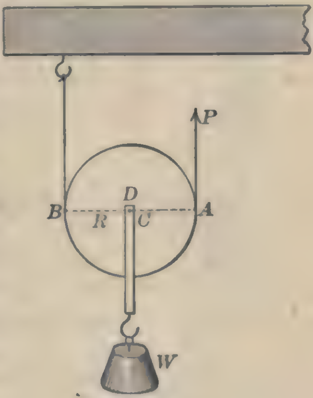

FIG. 80

109. Combinations of Fixed Pulleys. — Figure 81 shows how, by a combination of fixed pulleys, the horizontal pull of a horse can be used to raise a heavy weight. The mechanical advantage secured by the movable pulley would frequently be useless if it were not for combining with it one or more fixed pulleys by which the direction of the pull can be changed.

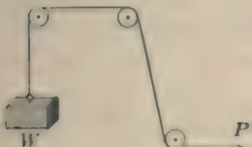

FIG. 81

110. Systems of Fixed and Movable Pulleys. — Where great weights are to be raised, systems of pulleys are used. Usually a number of "sheaves" or pulleys are arranged side by side in the same block, and a single rope is passed alternately around the sheaves in two of these blocks, called the "block and tackle." The weight is attached to the movable block A (Fig. 82), and since the rope is continuous there must be an equal stress on each branch between the blocks. If we let n represent the number of branches between the blocks ($n = 6$ in Fig. 82), then

$$P : W = 1 : n, \text{ or } P = \frac{W}{n} \qquad (31)$$

In some systems separate ropes are used. The law of equilibrium in any special case can be found by the application of the general law of machines.

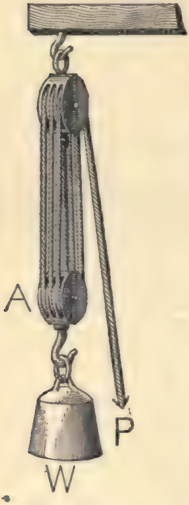

Fig. 82

111. The Inclined Plane. — Any plane surface that makes an angle with a horizontal surface forms an *inclined plane*. A ball placed upon a horizontal plane will retain its position and will press upon the plane with its entire weight. As soon, however, as one end of the plane is raised, the entire weight of the ball will not rest upon the plane, and it will begin to roll toward the lower end. A body may be supported on an inclined plane in three ways:

(*a*) When the power is applied parallel to the plane itself.

(*b*) When it is applied parallel to the base of the plane.

(*c*) When it is applied in a direction which is parallel neither to the plane nor to its base.

(*a*) If the power is applied parallel to the plane, it is evident that it has to balance only one component of the weight, the other being supported by the plane. To find these components it is only necessary to resolve the force WH, which represents the weight of the body, into two components, one, WF, to represent the pressure upon the plane, and the other, WK, to represent the component of the weight that must be balanced by the power P. From similar triangles

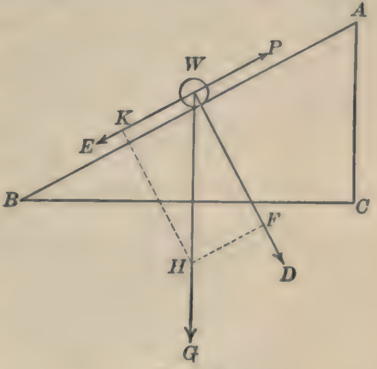

FIG. 83

$$WK : WH = AC : AB. \quad \therefore P : W = H : L. \quad (32)$$

In this formula H is the height and L is the length of the plane.

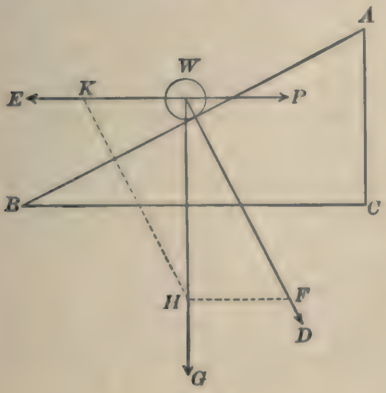

FIG. 84

(*b*) If the force which keeps the body in position acts parallel to the base, the components will be found by construction as in Fig. 84; and we have

$$WK : WH = CA : CB.$$
$$\therefore P : W = H : B. \quad (33)$$

(*c*) If the power acts in a direction that is parallel neither to the plane nor to the base, as WP in

Fig. 85 or Fig. 86, the solution can be worked out by trigonometry, if the angle at which the force acts is known. The correct result can also be obtained graphically by making *WH* some measured length, constructing the figure carefully, and measuring *WK* to the same scale as *WH*.

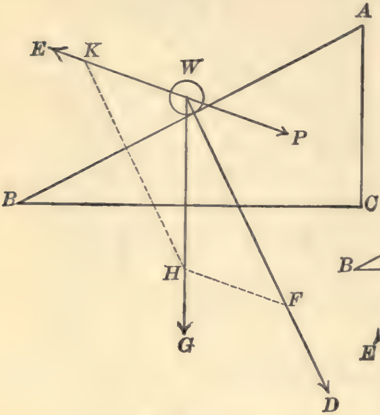

FIG. 85

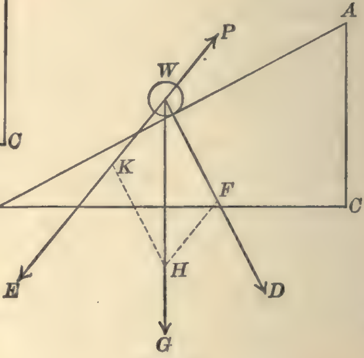

FIG. 86

In case (*a*) the force which keeps the body in place upon the plane does not affect the pressure of the body upon it. In case (*b*) this pressure is increased, and in case (*c*) it may be either increased or diminished. This may be shown by redrawing Figs. 83–86 so that *WH* shall be of the same length in all, and then comparing the various lengths of *WF*.

112. The Wedge is nothing more than a modified inclined plane. It is generally made with its base (which corresponds to the *height* of an inclined plane) perpendicular to a line drawn from the edge to the middle of the base. This means that it is made of two inclined planes placed base to base. The power is usually applied by the blow of a heavy body. Wedges are used in splitting logs and stone, raising heavy weights a short distance, launching ships, and similar operations. The method of applying the power, and the peculiar character of the resistance to be overcome, make it difficult to give any fixed law for the wedge, but approximately $P : W =$ one half the thickness (or base) of wedge : length of face, or

$$P : W = \tfrac{1}{2}\, T : L. \qquad (34)$$

113. The Screw consists of a cylinder of wood or metal about which is a thread. If the cross section of this thread is square, the thread is called a square thread; if triangular, it is called a V-thread. A good model of a square-thread screw can be made by winding a long strip of leather in a spiral around a wooden cylinder, and tacking it fast.

That the screw is a modified inclined plane may be seen by cutting a triangle out of paper, and winding it about a pencil as in Fig. 87. It will be seen that the hypotenuse, which represents the length of an inclined plane, forms the spiral thread of the screw. If CB is taken equal to the circumference of the pencil, then AB will be equal to the distance between the threads DE. This distance is called the *pitch*, and determines how far the screw moves at each revolution. The power is generally applied to a screw at the end of a lever, as the handle of a wrench. It is applied either to the screw, or to the nut, as in bolting two pieces of wood together.

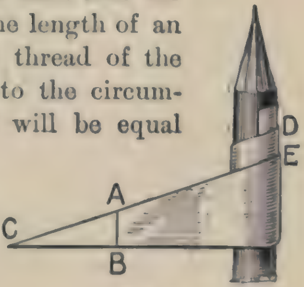

Fig. 87

114. The Law of the Screw cannot be determined unless the power is applied at some definite point on a lever.

By applying the general law of machines, the formula can be written

$$P : W = p : 2\,\pi R, \tag{35}$$

in which p is the pitch of the screw, and R is the radius of the circle through which the power moves.

115. Applications of the Screw. — Lifting jacks (Fig. 88), cotton and hay presses, the screw propeller of ships, ventilators, and air fans are familiar examples of the practical uses to which the screw is put, besides the constant use that is made of it in machinery and wood working. The spherometer and micrometer screw are examples of its use in scientific work.

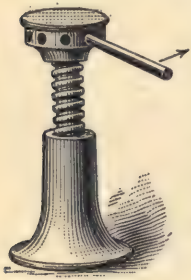

FIG. 88

116. Friction. — Whenever any body is put in motion, and then left to itself, its velocity will gradually diminish, and it will come to rest. This is due to *friction*, which is *the resistance that one body meets in moving over another under pressure.* Friction arises from inequalities in the surfaces in contact. If any means is taken to reduce these inequalities, either by making the surfaces smoother, or by filling up the depressions with some form of lubricating material, the friction is diminished.

Friction may be either *friction of rest* or *friction of motion.*

117. Laws of Friction. — Experiment has established the following laws:

I. *Friction of rest* is proportional to the pressure, and independent of the extent of the surfaces in contact.

II. *Friction of motion* is likewise proportional to the pressure, and independent of the extent of the surfaces;

and, within certain limits, it is also independent of the velocity of the motion.

118. Coefficient of Friction. — The coefficient of friction is found by dividing the force necessary to overcome the friction by the pressure normal to the surfaces in contact. A simple method of determining it is to place a block of known weight, *W*, upon a level board, and set it in motion by putting weights in a scale pan suspended as in Fig. 89. The coefficient of friction is expressed by the equation

$$f = \frac{P}{W}. \qquad (36)$$

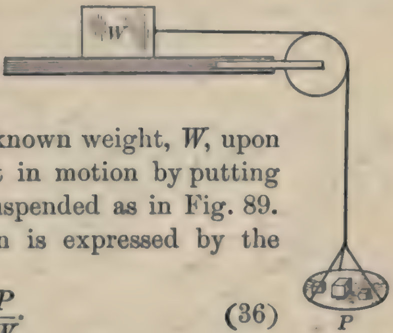

FIG. 89

PRACTICAL QUESTIONS AND PROBLEMS

1. Is a perpetual motion machine possible? Why?

2. Draw a figure of a lever of the first class, in which the moment of the power and the moment of the weight shall each be 20.

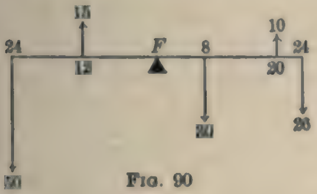

FIG. 90

3. Suppose a lever to be acted on by five forces, their directions and points of application being as in Fig. 90. Where must a force of 16 lb. be applied to keep the lever in equilibrium, if it acts downward? Where if it acts upward?

4. How much can a man who weighs 174 lb. lift, with a lever of the first class 10 ft. long, the fulcrum being 2 ft. from the weight?

5. A lever 19 ft. long weighs 18 lb. per running foot (each foot in length). Where must a force of 200 lb. be applied to balance a weight of 1600 lb. at one end, 3 ft. from the fulcrum?

6. With which class of lever will a force of 100 lb. raise the greatest weight, the lever being 12 ft. long and the weight arm 1½ ft. long? Prove your answer by a figure.

7. Which class of lever is represented by a pair of shears? Sugar tongs? A wheelbarrow? An oar in rowing a boat?

8. A ladder lies upon the ground with its foot against a house. Show by a figure how it changes from one class of lever to another when a man takes it by the top and raises it slowly to a vertical position by lifting successively on rungs nearer and nearer the foot.

9. Three men carry a stick of timber 16 ft. long, of uniform cross section. One of them has hold of one end and the other two have hold of a crossbar that passes under the stick. How far must this be from the end of the stick, that each man may carry the same load?

10. In a lever of the third class, 14 ft. long, with the power arm 2 ft. long, the power moves a distance of 9 in. How far does the weight move?

11. Make a drawing of a steelyard, showing how one side weighs pounds and the other ounces.

12. An engine is used to raise stone from a quarry with a wheel and axle. Suppose the drum is 4 ft. in diameter, and the axle 9 in. How heavy a stone can the engine raise when the pull on the rope over the drum is 1000 lb.?

13. How much pressure must be put upon the handle of a winch 14 in. in diameter, to raise a cubic foot of water, when the rope from the bucket is wound upon an axle 4 in. in diameter?

14. An anchor weighing 900 lb. is to be raised by the use of a capstan. The barrel of the capstan is 1 ft. in diameter and the handspikes are 4 ft. long, measured from the middle of the barrel. If 4 men are pushing at a distance of 6 in. from the ends of the handspikes, how much must each one push to raise the anchor? How far will each one walk to raise the anchor 75 ft.?

15. A horse is hitched to the end of a windlass bar 9 ft. long, and while moving a building walks at the rate of 2 mi. per hour. The barrel of the windlass is 10 in. in diameter. How far will the building attached to it move in 15 min.?

16. The sprocket wheel attached to the crank of a bicycle has 18 teeth, while the companion wheel over which the chain fits has 8. How many times does the rear wheel turn every time the pedals go round? How far does the bicycle go, the rear wheel being 28 in. in diameter? How many times must the pedals revolve per minute when the wheel is going at the rate of 10 mi. per hour?

17. Describe the change of motion in a sewing machine.

18. Show by a figure the arrangement of ropes in a system of pulleys with which a man pulling downward with a pull of 150 lb. can balance 900 lb.

19. A barrel of flour is being rolled into a doorway 3½ ft. above the ground on a plank 16 ft. long. How much power must be applied parallel to the plank to keep the barrel from rolling back? What is the pressure on the plank?

20. A hogshead of molasses weighing 600 lb. is being rolled up a gangplank 18 ft. long, one end of which is 7 ft. higher than the other. The rope, one end of which is fastened at the top of the plank, passes around the hogshead and the power is applied at the other end, as in Fig. 91. What power is required to roll the hogshead up the plank?

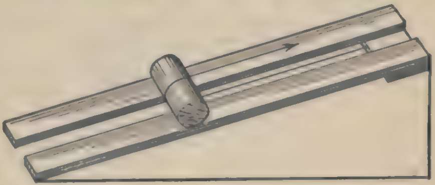

FIG. 91

21. Show by a figure that when a ball is kept from rolling down an inclined plane by a power directed horizontally against its center, the pressure on the plane is increased.

22. A screw press has a handle 10 in. long and the screw has 8 threads to the inch. How much pressure will a pull of 75 lb. exert, if it is applied 1 in. from the end of the handle?

23. How many jackscrews, with a pitch of ¼ in. and handles 15 in. long, must be used to raise a weight of 100,000 lb., if the greatest pull on each handle cannot exceed 50 lb.?

24. A wheel 4 ft. in diameter is attached to an axle 6 in. in diameter, and it is found that it requires 70 lb. to put in motion 500 lb. attached to the axle. What is the efficiency?

25. A piece of cast iron weighing 60 lb. was placed upon a level oak plank, and it was found to require a pull of 37½ lb. to slide it over the plank. What is the coefficient of friction between them?

LABORATORY WORK

1. Cut a stick 82 cm. long, 4 cm. wide, and 2 cm. thick, of uniform density, and bore a small hole just to one side of the middle line drawn from end to end, but in the middle of the length. Call this point zero, and make a thin saw cut 1 mm. deep every 10 cm. in each direction. Drive a wire nail, from which you have filed the head, into a post for a support for the lever, and see that it balances accurately. Make a loop of strong thread and place in each notch. Make two tin scale pans, weigh them, and stamp their weight on each. Hook one pan on each side of the fulcrum in the different loops, and with additional weights make a study of the moments of forces and the law of the lever. An accurate way to read the zero position of the lever is to drive a pin in one end, and just back of this fix a mirror vertically. On the face of this paste a triangle of paper with the point directed toward the image of the pin when the lever is horizontal. Then whenever the pin covers its image at the point of the triangle, the lever will be in the position of equilibrium.

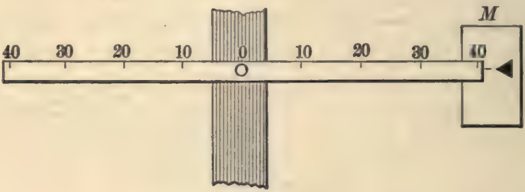

FIG. 92

2. The efficiency of a lever depends upon the amount of friction at the support. Make a series of experiments to determine the efficiency of the lever in No. 1, as follows: Place a certain weight at 10 cm. from the fulcrum, and balance it by a weight at 40 cm. Find how much can be added before the lever will begin to move. Determine the efficiency for various loads, the points of suspension being the same. Draw the curve for efficiency, laying off loads on X and efficiency expressed as per cent on Y.

NOTE. — Steel bicycle balls are very uniform in weight, and may be used as weights in many experiments.

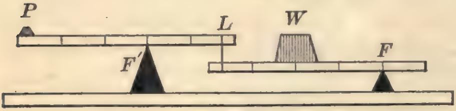

FIG. 93

3. Mark 10-cm. divisions on two rods of uniform cross section, and a half meter long, or more. Rest them on fulcrums F and F'. Fasten the short arm of one to the long arm of the other with a loop of strong cord or fishing line, as at *L*. Place a weight *W* on the first lever, and balance it with a small weight *P* on the other. From the relation of *P* to *W*, and the relations of the different lever arms, write the law for the compound lever.

4. If you have no wheel and axle, make one by getting four wooden disks turned, each with a quarter-inch hole in the center. Drive these on a brass rod, and screw them together. Make a number of experiments with different powers and weights, and from these draw the curve of efficiency of the wheel and axle, as in No. 2.

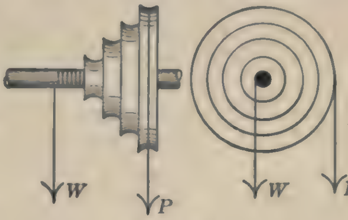

FIG. 94

5. Arrange a single fixed pulley as in Fig. 79. Attach a spring scale at *P*, and find its readings for different values of *W*, both when *W* is stationary, and when it is rising. Explain the different readings of the scale for the two conditions.

6. Make the same experiment with a movable pulley, as shown in Fig. 80. What differences do you notice in the values of the scale readings for different values of *W*?

7. Make a number of combinations of pulleys with those you have in the laboratory, and verify Formula 31.

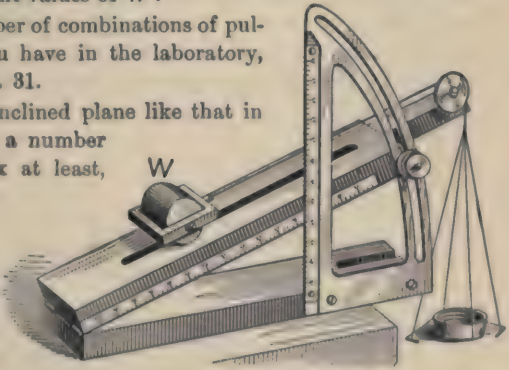

FIG. 95

8. Procure an inclined plane like that in Fig. 95, and make a number of experiments, six at least, with the plane raised to different heights. Is Formula 32 correct? The weight *W* is made of a brass cylinder, together with a wire in each end for an axle, and a frame by which to draw it. The weight can be stamped on the end, and this will be the value of *W* in all experiments.

9. In No. 8, no allowance was made for friction. This may be done by using a spring scale in place of the pulley and scale pan. Pull steadily so that the weight W shall move up the plane with a uniform rate, and take the scale readings. Take the readings when it is moving down at the same rate. The average of these will be the true value of P. Make this experiment with at least five different elevations of the plane.

10. Arrange a fixed pulley at one end of a smooth board, as in Fig. 96. In a block $1\frac{1}{2} \times 3 \times 4$ inches, fix two screw hooks in the end, so that a cord running from one of them to the pulley will be parallel to the base when the block is lying on its side, and, when running from the other, will be parallel to the base when the block is on its edge. Attach a scale pan to the end of the cord for the weight P. Fix the board so that it is exactly level. Weigh the block, and stamp or write the weight upon its end. Place weights upon the block until the combined weight is 100, 200, 300, etc., grams. Find in each case the weight that has to be placed upon the scale pan in addition to its own weight to make A move slowly and uniformly, when the board is jarred by being constantly tapped with the fingers. From these experiments determine the coefficient of friction. Determine whether the friction varies when the block is placed upon its edge.

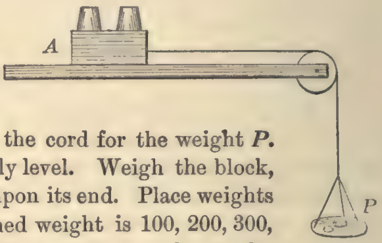

Fig. 96

11. Since the coefficient of friction is expressed by the ratio of P to W, and since this ratio in the inclined plane is the ratio of H to B, it is possible to make a form of inclined plane by which the value of f can be read directly. Make an inclined plane, as in Fig. 97, hinged at B. At the end B, of the base BG, place a wooden cylinder with a brass rod $\frac{1}{4}$ in. in diameter for an axle. Bend this rod twice at right angles for a handle. Fasten a cord at A, run

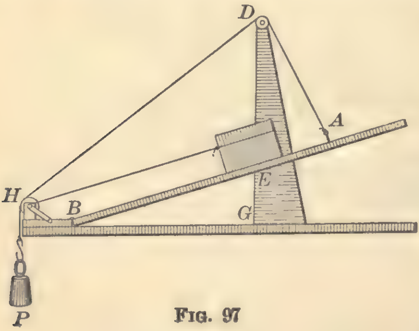

Fig. 97

it over a fixed pulley at D, then twice around the wooden cylinder at H, and suspend a weight P from the other end. By turning the handle of the cylinder the plane BA is raised until the block begins to slide freely. The height GE is read at this point. In order to keep the block in constant motion a fine wire is fastened to it, and then wound around the axle of the cylinder. If the base BG to the foot of the upright DG is made 1 m. long, and if the upright is divided into millimeters, then will the distance GE, cut off by the plane when the block begins to slide down it, give the value of f directly.

For example, $$f = \frac{GE}{GB} = \frac{271}{1000} = .271.$$

Find f for blocks of different material.

12. Select a smooth hard-wood board 2 ft. long and 1 ft. wide. Select a second similar board about 6 × 8 in. Place the second board upon the first, and load it until the board and its load weigh 1 kg.

Attach a cord and spring scale to the upper board, and pull until the friction is overcome. Read the scale just as the board starts, and again while it is kept in uniform motion. Now place a dozen quarter-inch bicycle balls between the boards, and determine the friction again. How do the sets of readings compare? Determine the value of f for rest and motion. What per cent have these values been changed by the use of the balls?

CHAPTER IV

LIQUIDS

I. MOLECULAR FORCES IN LIQUIDS

119. Cohesion. — *Cohesion, in liquids, is the mutual molecular attraction of the particles of a liquid for one another.* Since water is the most common liquid, the experiments that follow will be made with water unless there is a special reason for using some other liquid.

If a glass rod is dipped in water and then removed, a drop will form on the end of the rod, and will grow larger and larger as the water runs down the side, until the weight of the drop becomes great enough to break it away from the rod, when, as it falls, it takes the form of a sphere. In this experiment cohesion does two things: it keeps the water from falling as soon as it runs down the side of the rod; and it gives the drop the form of a sphere.

120. Spherical Form of Liquids. — Whenever liquids are subjected to cohesion alone, they assume the spherical form. This is readily seen by noting the shape of raindrops. Shot owe their form to the fact that molten lead is poured through sieves at the top of a high tower, and is thus separated into small masses, each of which assumes the form of a sphere. This formation can be studied by making a mixture of alcohol and water, using such proportions that the

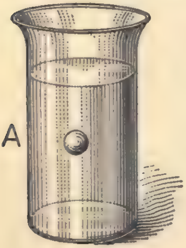

FIG. 98

mixture will have the same specific gravity as olive oil. Introduce a small quantity of the oil below the surface of the mixture, by the use of a glass tube, and the oil will assume the globular form, as in Fig. 98.

EXPERIMENT 34. — Cover a smooth board with a fine dust, like lycopodium powder or powdered lampblack. Drop a small quantity of water upon it from a height of 2 or 3 ft., and the water will scatter and take the form of spheres. Why?

NOTE. — Lycopodium powder — which is made up of the spores from certain plants — can be obtained from any drug store. A few cents' worth will be found very useful for many experiments.

121. The Surface of a Liquid. — EXPERIMENT 35. — Make one end of a small brass wire very sharp, and bend it into the form of a hook. Put the hook into a glass of water so that the point shall be below the surface. Bring the point of the hook up to the surface, and observe that the point, before breaking through the surface, lifts it as if it were a thin flexible blanket stretched over the water. Place the eye at *E* and observe that the reflection of the sky, seen from the surface of the water, is distorted at the point where the hook lifts the surface.

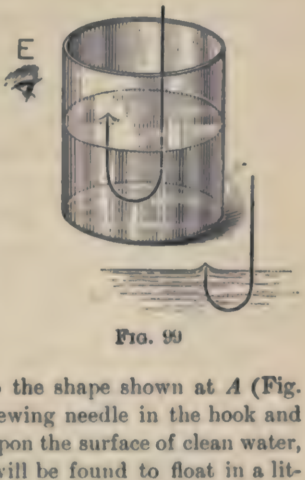

FIG. 99

EXPERIMENT 36. — Bend a wire into the shape shown at *A* (Fig. 100). Place a sewing needle in the hook and lay it carefully upon the surface of clean water, and the needle will be found to float in a little depression upon the surface, as shown in the lower part of the figure.

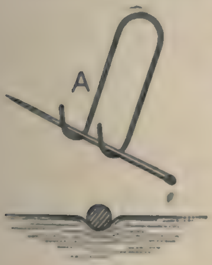

FIG. 100

The above experiments show quite conclusively that the surface layer of a liquid differs from any other layer. If the needle is placed below the surface, it will sink at once.

122. Surface Viscosity. — Whenever a liquid has been exposed to the air for some time, it becomes more or less viscous and the surface becomes difficult to break through.

If a sewing needle is magnetized and placed upon the water as in Experiment 36, it will gradually move around until it points to the north. But instead of moving through the surface it carries the whole surface with it. This may be seen readily by scattering lycopodium powder upon the water before the needle is laid upon it, and then observing the motion.

A bubble coming through the surface of a boiling liquid will, if the surface is viscous, scatter the liquid in a shower of small drops. Alcohol, which has little surface viscosity, is frequently added to boiling liquids to prevent this action. The surface of oil has greater tenacity than the surface of water, and for this reason oil is sometimes thrown upon the water around a ship during a storm. The effect of this is to smooth out the surface as though a strong elastic blanket were stretched over the water; and the waves are then kept from breaking over.

123. Surface Tension. — Let us study the attractions acting upon a molecule at different distances from the surface, as shown in Fig. 101. At *A* the molecule is attracted equally in all directions by the molecules that are within the distance of molecular attraction; hence it can move readily in any direction. At *B*, very near the surface, the horizontal attractions are equal

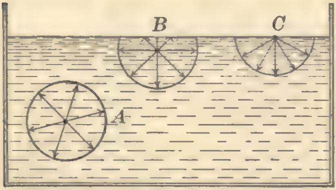

Fig. 101

in all directions, but the downward attraction is greater than the upward. At the surface the molecule C has no upward attraction, and hence it is held in place by the downward force. As this is true of every molecule on the surface, the result is a tension upon the surface layer much greater than upon any other layer.

Surface tension varies with the liquid and with the temperature of the liquid. The surface tension of pure water is very great, compared with that of most other liquids, as is illustrated by the following experiments:

EXPERIMENT 37. — Pour some hot water into a shallow dish, like a soup plate. Cover the surface with pepper. Hold a small piece of butter in the surface of the water at the middle, and observe how the pepper goes away from the melting butter to the sides of the plate.

EXPERIMENT 38. — Spread a thin layer of clean water upon a glass plate, and then let a drop of alcohol fall upon the middle of it. The water will at once retreat, leaving a space around the drop of alcohol. Why?

EXPERIMENT 39. — Spread a thin layer of water upon a glass plate, and over the middle of it hold a glass rod with a drop of ether hanging to the end. Notice that the absorption of the ether vapor by the water reduces the surface tension of the water at this point, and that the water there is pulled away by the tension of the surrounding water.

In all experiments on surface tension great care must be taken to keep the water, and everything that comes in contact with it, clean. The touch of a greasy finger is enough to change the surface tension of the water.

124. Films. — By a study of Fig. 101, we have seen that the tension diminishes as we go from the surface into the body of a liquid. If we make the thickness of the liquid mass very little, and give to it two free surfaces, the phenomena may be studied to better advantage.

Experiment 40.—Make a strong solution of soap by dissolving castile soap in water until a large bubble can be blown. Bend a piece of iron wire so as to form a square frame with a handle, and from one side of the frame hang a loop made of one strand of a silk thread. Dip this frame in the soap solution, and the loop will hang as in Fig. 102. Remove the film within the loop by touching it with the point of a piece of blotting paper, and the loop will at once spring out into the form of a circle, as in Fig. 103. Why?

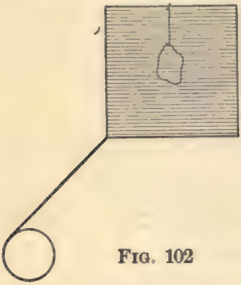

Fig. 102

Note.—The film will stick better to a rusted wire than to a bright one.

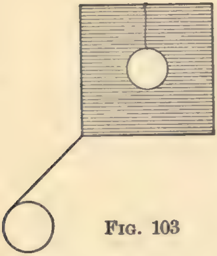

Fig. 103

Experiment 41.—Using a clay pipe or a glass tube, and the solution of Experiment 40, blow a good-sized bubble. Remove the tube from the mouth, and hold the end of it toward the flame of a lighted candle. The pressure exerted by the surface tension of the film will force out a current of air strong enough to blow the flame to one side. What change takes place in the size of the bubble?

125. Capillarity.—If a glass rod is dipped in water, the water close to it will rise to a considerable height above the general surface of the water, as in Fig. 104. Any molecule of the water, as *A*, is subject to three forces: the attraction of the mass of the liquid, *P*; the attraction of gravity, *Q*; and the attraction of the glass, *S*. The direction and intensity of the resultant, *R*, will depend upon the relative values of these forces; and the surface of the liquid at *A* will be perpen-

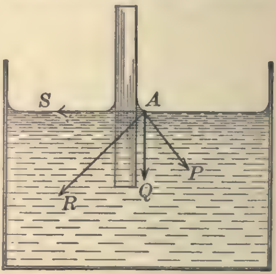

Fig. 104

dicular to the direction of this resultant. If the attraction of the glass is relatively great, the direction of the resultant will be as in Fig. 104, and the surface of the liquid will be concave, while, if it is relatively small, as in Fig. 105, then the surface of the liquid will be convex, as when a glass rod is thrust into mercury.

If two plates of glass are thrust into water, with their faces parallel to each other, the liquid will rise between them, the height being greater, the nearer the plates are to each other. If the plates are brought together at one edge while the other is opened out, as in Fig. 106, this varying height will be shown in the form of a curve, highest at the angle, and lowest at the outside edge.

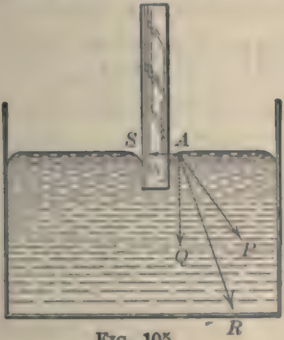

FIG. 105

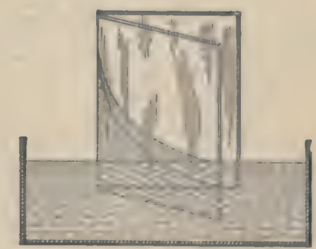

FIG. 106

EXPERIMENT 42. — Pour some clean water into a beaker, and thrust one end of a piece of clean glass tubing below the surface of the water. The water will rise on the inside of the tube to a considerable height above the water in the beaker. On removing the tube it will be found to be wet. Repeat the experiment with a tube of half the diameter, and the water will rise twice as high.

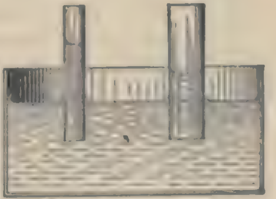

FIG. 107

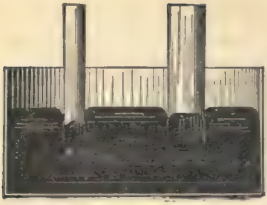

FIG. 108

EXPERIMENT 43. — Pour clean mercury into a dish, and repeat the process of Experiment 42, using clean glass tubes of the same sizes as before. Observe that the surface of the mercury is convex and that it is depressed in the tubes. Notice also that the glass tubes are *not* wet by the mercury.

126. Capillary Tubes. — The tubes used in the preceding experiments — if very small — have received the name of *capillary tubes*, from the Latin word *capillus*, which means "hair." The attraction which causes liquids to go up into these minute openings is called *capillary attraction.*

The results of such experiments as 42 and 43 lead to the following laws:

I. *When a liquid wets the surface of a tube placed in it, the surface of the liquid will be concave, and the liquid will rise in the tube. When the liquid does not wet the tube, the surface of the liquid will be convex, and the liquid will be depressed in the tube.*

II. *The elevation or the depression varies inversely as the diameter of the tube.*

Further experiments would determine a third law, as follows:

III. *The elevation or the depression decreases as the temperature rises.*

EXPERIMENT 44. — Heat a piece of glass tubing to redness, and draw into a tapering tube. Introduce a globule of clean mercury and measure the distance of the end of the mercury from the small end of the tube. Remove the mercury and introduce a like quantity of water and measure again. Observe that the tendency of the mercury is to move toward the larger end, while the water moves toward the smaller end. Why?

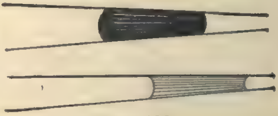

FIG. 109

127. Absorption. — Whenever a liquid is brought in contact with a porous solid, and wets it, the liquid immediately begins to pass into the pores of the solid; this process is called *absorption*. Blotting paper absorbs ink, and a lamp wick, oil. When once absorbed the liquids cannot be entirely removed by pressure. A sponge can never be pressed dry, but becomes dry only when evaporation takes place. It is evident that absorption is a capillary phenomenon and that every pore in a porous substance acts as a capillary tube.

128. Diffusion of Liquids. — Whenever two liquids like oil and water are poured into a bottle and thoroughly shaken, they will separate into two distinct layers very soon after the shaking is stopped. The separation of oil and water is nearly perfect; but if ether and water are shaken together, and then allowed to come to rest, while there will still be a separation, the layer of water will contain some ether, and the layer of ether will contain some water.

EXPERIMENT 45. — **Fill a small jar three fourths full of water colored with blue litmus, and pour a small quantity of sulphuric acid carefully into the bottom of the jar through a thistle tube. The litmus will be colored red wherever the acid comes in contact with it. If now the jar is kept in a quiet place, the acid will pass through the litmus solution, and after a time the entire contents of the jar will be red.**

This action, which takes place against the force of gravity, and which is visible to us by the change of color only, is called *diffusion*. Substances diffuse at different rates, depending upon the temperature and density of the solution.

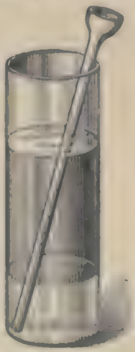

FIG. 110

129. Osmose. — When two solutions of different substances are separated by a porous membrane, each will pass through the membrane into the other with more or less freedom. This process is called *osmose*.

EXPERIMENT 46. — Tie a piece of parchment paper over the end of a thistle tube and fill the tube part way up the stem with a strong solution of copper sulphate. Thrust it into a beaker containing water, and fix it in such a position that the liquids stand at the same height, both inside and outside the tube. Set the beaker aside for some time. Does any change take place in the height of the liquid within the tube? Is there any change in the color of the water? Does the experiment prove that osmose has taken place? Do the liquids pass through the membrane at equal rates?

130. Dialysis. — Experiment shows that those substances that have a crystalline structure and can be dissolved easily in water will diffuse through a porous membrane readily. Substances like gum and starch, which are not crystalline, diffuse very slowly. Substances of the first class are called *crystalloids*, and those of the second class are called *colloids*.

If a mixture of crystalloids and colloids is placed in a dish with a membranous bottom, and floated upon water, the crystalloids will pass through into the water, and the colloids will remain. This process is called *dialysis*. One of its uses is to detect the presence of arsenic in the contents of the stomach.

PRACTICAL QUESTIONS AND PROBLEMS

1. Which is the larger, a drop of water or a drop of olive oil? Why? Do we get equal quantities when we pour out a given number of drops of different medicines?

2. Why does the silk loop in Fig. 103 take the form of a circle?

3. Suppose the direction of R in Fig. 104 is vertical, what kind of a surface will the liquid have?

4. Will ink pass readily into the surface of a sheet of glazed paper? Into a newspaper? Why?

5. Give five examples of capillary action.

6. Which has the greater surface tension, water or alcohol? How will you prove your answer?

7. If a glass tube, oiled on the inside, is thrust into a beaker of water, will the water rise or fall inside the tube? Why?

8. If you fix a capillary tube vertically, with its lower end in water, and then gradually heat the water, what will be the result? Could a curve be made showing the relation between temperature and height of column?

LABORATORY WORK

1. Fill a small bottle nearly full of water. Pour in a small quantity of olive oil, and shake vigorously. Explain the form of the drops of oil as it gathers again after being shaken.

2. Fill a large beaker nearly full of water. Put one end of a small flexible rubber tube near the bottom of the water and blow gently into the other end. Observe the shape of the bubbles as they rise, and explain.

3. Make a number of cork balls and float them upon the surface of water. Can you keep them apart? Explain.

Make a number of wax balls, and with them repeat the experiment.

4. Take one cork ball and one wax ball, and float them on water. Do they act toward each other as two cork balls would?

5. Make a number of iron wire frames representing different geometrical solids, like Fig. 111. Dip them into a soap solution and make a study of the various forms the films can be made to assume.

6. Pour some soap solution into a large shallow dish. Blow into it through a glass tube and form a mass of bubbles. Observe the forms the bubbles take as they come in contact with one another. Make drawings of them.

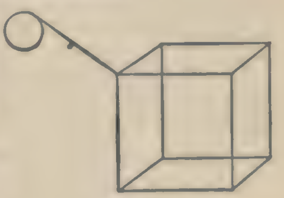

FIG. 111

7. Draw from a piece of soft glass tubing a fine capillary tube. Break out a piece about a foot long, having a uniform diameter, and put one end in water. Moisten the inside of the tube by drawing it

full of water and blowing it out again. Hold the tube vertically and measure the height of the water in it. Draw the tube gently from the water and notice whether there is any change in the length of the water column. Break the tube and, taking a piece an inch shorter than the length of the measured water column, put it in water as before. Does the water come out at the upper end of the tube? Explain.

8. Select a glass tube a half inch or more in diameter. Heat one end of it in the flame of a Bunsen burner, and draw about two inches of it out into a small tube. Dip the large end in water, and lower the tube until the small end is full. Raise the tube until the small end is above the surface of the water, as at *A*. Why does not the water in the tube fall to the level of the water outside?

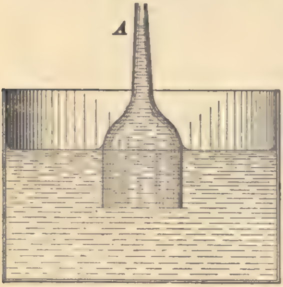

FIG. 112

9. Arrange a diffusion jar as in Experiment 45. Fix a meter stick in a vertical position by the side of the jar. Begin to take readings of the position of the line of division between the colored liquids as soon as possible after putting in the acid, and at intervals afterward. Make a record of the readings and of the time between each two readings, and from these make a curve, laying off time on the axis of *X*, and heights above the first reading on the axis of *Y*. Is the curve a straight line? What does this mean?

10. Procure a small porous cup such as is used for a battery cell, and fit in the open end a rubber stopper with one hole. In the stopper fit one end of a glass tube *T*, bent as in Fig. 113. Pour mercury into the end of this tube and let it come to rest at *A*. The heights in the two branches can be made the same by letting a little air out of the cup. Lower the cup into a beaker of water and observe the change in the level at *A*. Explain this action. Measure this pressure by putting a scale back of the tube at *A*.

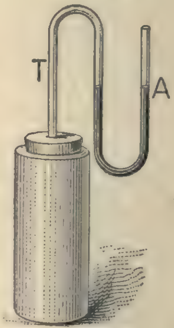

FIG. 113

II. THE MECHANICS OF LIQUIDS

131. Transmission of Pressure by Liquids. — Whenever pressure is brought to bear upon a solid, the molecules, being unable to move freely over one another, will transmit the pressure, undiminished, in one direction only. In the case of liquids, however, the free movement of the molecules over one another secures the transmission of pressure, without change, in all directions.

EXPERIMENT 47. — To a thin glass bottle fit a straight cork, of such a size as to go into the neck snugly. Fill the bottle with water. Insert the cork and bring pressure to bear upon it by a lever as in Fig. 114. The shattering of the bottle shows that the pressure was transmitted in all directions.

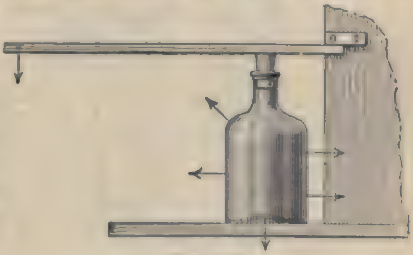

FIG. 114

The action of the molecules of a liquid in transmitting pressure may be illustrated by filling a bottle with peas or shot and pressing upon the top layers.

Since each pea or shot does not lie directly upon another, but rather in a depression left between those in the next lower layer, a vertical force acting upon any pea or shot will be resolved into other forces in the directions of the points of contact between it and the peas or shot which it touches.

Since liquids are perfectly elastic, and since their molecules move over one another with perfect freedom, the resultant of all the pressures acting upon a molecule will be the same as if the original pressure acted upon it. As a result, these considerations lead to the following law:

132. Pascal's Law. — *Pressure exerted upon any part of an inclosed liquid is transmitted undiminished in all directions. This pressure acts with equal force upon all equal surfaces and at right angles to them.*

EXPERIMENT 48. — Get a brass tube about 25 cm. long and 10 cm. in diameter. Drill holes *A* and *B* in the side. Fit each with a rubber stopper with one hole. Fit the stoppers with small glass tubes of the shape shown in Fig. 115. Fit a large rubber stopper and tube *C* into the bottom of the tube, and a piston and tube *D* into the top. Pour mercury into the U-tubes to act as gauges for measuring the pressure. Fix a pan at the top of the piston rod for holding weights, and fill the brass tube with water. Stick strips of gummed paper along the straight parts of the U-tubes. Mark the positions of the upper end of the mercury. Add weights to the scale pan and mark again. The changes in the column of mercury will measure the pressure. Are these changes equal?

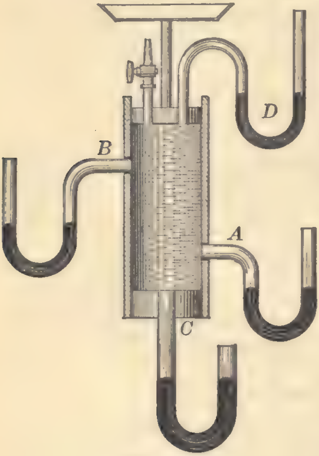

FIG. 115

133. The Hydraulic Press. — An important application of the principle stated in Pascal's Law is made in the hydraulic press. The essential features of the machine are shown in Fig. 116. Two pistons or plungers *A* and *B* pass through water-tight collars into cylinders *C* and *D*. The piston *A* is moved by the lever *G* by applying the power at *P*. The body to be compressed is placed between the platform *H* and a stationary framework above it. The action is as follows: Both cylinders and the connecting tube being full of water, the piston *A* is forced down, the pressure on the water in *C* closing the valve *E*, and forcing the valve *F* open. The water displaced by *A* is forced through *F*, and passes into *D*, where it pushes *B* up, and compresses *K*. When the piston *A* is raised, the back pressure of *B* upon the water closes *F*. *E* opens, and water from *M* passes through it, keeping *C* full. The next stroke simply repeats the action.

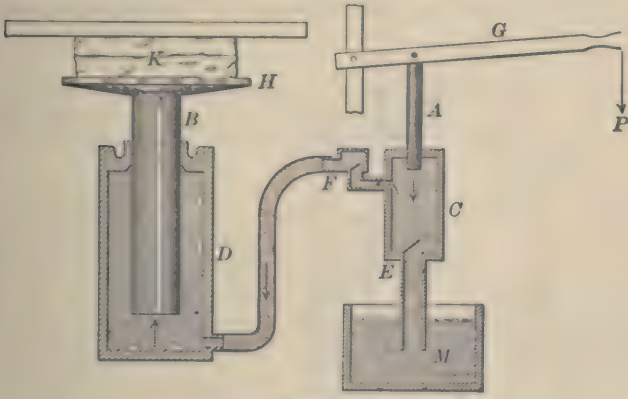

FIG. 116

The fact that water is almost incompressible and perfectly elastic is of very great importance in connection with this machine. A pressure of 100 lb. to the square inch compresses water only .00033 of its original volume, and, on the removal of the pressure, that volume is immediately restored.

134. Pressure Due to Gravity. — The principle stated in Pascal's Law holds whether the force employed is due to the pressure of weights placed on a piston resting upon the surface of the liquid, or to the pressure of an added layer of water. When a liquid is at a uniform temperature throughout, the entire mass is in a state of equilibrium, and there are no internal currents, as can be seen by mixing some heavy sawdust through the water. This means that *the pressure exerted at any point in a liquid by its own weight is equal in all directions.*

135. The Relation of Pressure to Depth. — Since every horizontal layer of a liquid has to support the weight of the liquid above, we may write as a result the following laws:

I. *The pressure in any layer is proportional to its depth.*

II. *The pressure is the same at all points in the same horizontal layer.*

EXPERIMENT 49. — Bend three glass tubes into the forms shown in Fig. 117. Into the tube *A* pour a small quantity of mercury. Lower it slowly into a vessel of water. Any changes in the level of the mercury will indicate changes in the pressure. Does the pressure increase with the depth? Hold the three tubes in one hand in such a way that the three openings are at the same level, and lower the tubes together into the water. Is the change in the mercury level in each tube the same? Why?

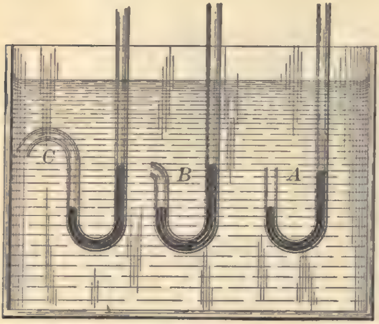

FIG. 117

136. Vertical Downward Pressure. — In the case of a liquid contained in a vessel with vertical sides, the weight of each layer is transmitted undiminished to the layers below. Hence each layer bears the weight of the liquid above it, and the total pressure on the bottom will be the weight of the liquid in the vessel.

Experiment 50. — Procure three glass vessels of the shape shown in Fig. 118, each having the same size of base. Grind the base of each so that when the disk *D* is held against it the joint will be water-tight.

Fasten the tube *A* in a vertical position with the standard and ring *K* so that the bar *DE* will be horizontal when the base of *A* and the disk *D* are in contact.

Put weights upon *E* and pour water in *A*. Put weight enough upon *E* so that the disk *D* will be kept pressed against the bottom of *A* until *A* is nearly full of water. Adjust the screw point *H* until it just touches the surface of the water in *A* when it begins to leak out at *D*. Remove *A* from the ring *K* and substitute *B* and *C* in turn, and it will be found that the water will push off the pan *D* at exactly the same height of water when the same weights are placed upon *E*.

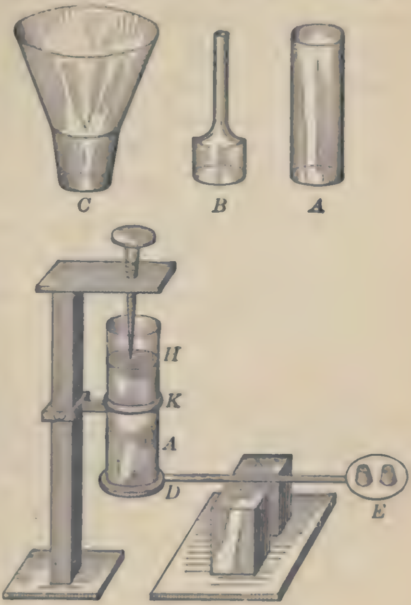

Fig. 118

The above experiment proves that *the pressure on the bottom of a vessel containing a liquid is entirely independent of the shape of the vessel; with a given liquid it depends solely upon the depth of the liquid and the area of the base.*

Experiment 51. — Replace the tube *A*, and use a solution of salt, which is heavier than water, and it will be found to require less height for the same pressure.

From this we see that *the pressure on the bottom of a vessel depends also upon the density of the liquid.*

137. Pressure on the Side of a Vessel. — When a liquid is contained in a vessel with vertical sides, the pressure at any point of the side depends upon its distance from the surface of the liquid. The total pressure on the sides of the vessel is the sum of all these pressures, which vary from zero at the surface to a maximum at the bottom. The rule for finding the pressure on any submerged surface may be written as follows:

The pressure of a liquid upon a submerged surface is equal to the weight of a column of the liquid having the area of the surface for its base, and the depth of the center of gravity of the given surface below the surface of the liquid for its height.*

This rule applies to all submerged surfaces, whether vertical, horizontal, or inclined, plane or curved. If the surface is the horizontal base of the vessel, the height of the column will be the total depth of the liquid.

The above law may be expressed in a formula as follows:

$$\text{Pressure} = HaW, \tag{37}$$

in which H is height, a is area of base, and W is the weight of a cubic foot or unit volume of the liquid.

A cubic foot of water weighs about 62.5 lb., or 1000 oz.

138. Center of Pressure. — The center of pressure on a submerged surface is the point of application of all the forces acting upon it, due to the pressure of the water. If we have a rectangular side to a vessel containing water, since the pressure increases from the top to the bottom, it is evident that this point must be below the middle of the side. A convenient way to determine the position of this point is as follows. Lay off a line CB perpendicular to the side AB to represent the pressure at B. Draw the line CA. Any lines, as ED and GF, drawn perpendicular to AB will represent the pressure at the points D and F respectively. Why?

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* See page 64. In plane surfaces the center of gravity is the center of area.

The area of the triangle ABC will represent the entire pressure upon AB, and the center of pressure will be at the point H where the perpendicular from the center of area of the triangle meets the side AB. It is evident that this point will be in such a position that $AH = \frac{2}{3} AB$, since the center of area is at O, a point such that $AO = \frac{2}{3} AK$.

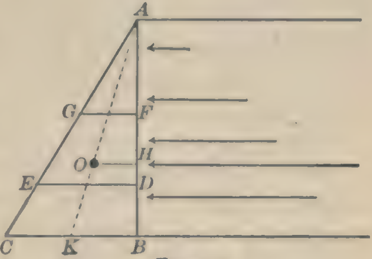

FIG. 119

If the side AB is movable, a support at H will prevent either the top or the bottom from being pushed out.

139. The Surface of a Liquid at Rest. — We have already seen that when the resultant of all the forces that act upon any point in a liquid is zero, there will be a condition of equilibrium, and the liquid will be at rest.

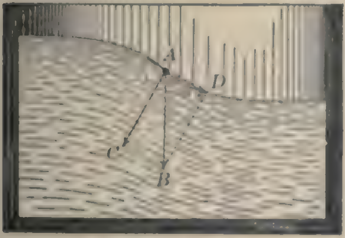

FIG. 120

In order that the surface of a liquid may be at rest, it must be horizontal. Suppose that the surface is not horizontal, as in Fig. 120. The force of gravity AB, which acts upon any molecule upon the surface, as A, may be resolved into two forces, one of which, *AC*, is perpendicular, and the other, *AD*, parallel to the surface. Now the first, *AC*, will be opposed by the resistance of the liquid, while the other, *AD*, will move the molecule to a lower level. When the surface is horizontal, the action of gravity is perpendicular to it, and since there can be no component parallel to the surface, no movement will take place, and the liquid will remain at rest.

140. Equilibrium in Communicating Vessels. — Whenever a number of vessels are connected, and water is poured into one of them, it will, when it comes to rest, stand at the same height in all. Neither size, nor shape, nor position affects the result. It is in accordance with this principle that water seeks its own level, that fountains play, and that water is distributed in the modern systems of water distribution in cities.

141. Superposed Liquids. — If two or more liquids having different densities are poured into a jar, they will come to rest in the order of their densities, with the surfaces of each separating them horizontally. Those liquids that will not mix must be chosen for the successive layers. Mercury, water, oil, and alcohol, when poured into a test tube, will come to rest in the order named. If they are to be poured in in such a way that the alcohol and water can come in contact, the water should have dissolved in it some sodium carbonate. It is an easy matter to find a solid that will sink through one liquid layer and float on another, as a bicycle ball on the top of the mercury and at the bottom of the water.

142. Vertical Upward Pressure. — It has been shown in Experiment 49 that the upward pressure at any point below the surface of a liquid is equal to the downward pressure.

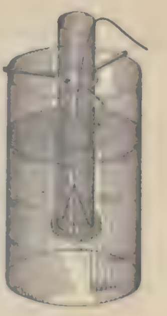

FIG. 121

EXPERIMENT 52. — Select a glass tube like a lamp chimney, and a glass plate or disk just large enough to cover the end of the tube. Grind the end of this tube, and the glass plate, to a water-tight joint with emery. Fasten three cords to the plate or disk, and to a single cord, as in Fig. 121. Hold the disk in place over the bottom of the tube with the cord, and push the tube down into the water in a jar. The upward pressure will hold the disk in place without the cord. Pour water into the tube until the disk falls off, when the weight of the water poured in, added to the weight of the disk, will measure the upward pressure.

PRACTICAL QUESTIONS AND PROBLEMS

1. If the diameter of the small plunger in a hydraulic press is 1 in., and that of the large plunger is 6 in., how much pressure will a force of 60 lb. on the former exert on the latter? How much per square inch?

2. Suppose the force in problem No. 1 to be applied by pressing down on the lever shown in Fig. 116. How great a pressure is required by the hand if the lever is 3 ft. long, and the fulcrum 6 in. from the piston?

3. Draw a figure similar to Fig. 116, showing the proportions that may be used so that a pressure of 10 lb. at *P* will produce a pressure of 1600 lb. at *B*.

4. Compute the pressure on the bottom, sides, and ends of a box 4 ft. long, 2 ft. wide, and 1½ ft. high, when filled with water.

5. Compute the pressure on the bottom, sides, and ends of the same box when it is two thirds full of water.

6. A bottle 6 in. in diameter is filled to a height of 8 in. with sulphuric acid, which is 1.8 times as heavy as water. What is the total pressure upon the bottle?

7. Find the entire pressure upon a standpipe 60 ft. high and 25 ft. in diameter, when four fifths full of water.

8. What is the pressure on a gate 2 ft. long and 1½ ft. high, in

the side of a dam, when the water stands at a height of 18 ft. above the top of the gate?

9. Suppose the head of water in a system of waterworks is 150 ft. above the distributing pipes; what is the pressure upon every square inch of the pipes?

10. A vessel 40 cm. high, 18 cm. long, and 10 cm. wide has a circular window 6 cm. in diameter placed in one side with its upper edge at a distance of 32 cm. from the top of the vessel. Find the entire pressure on the vessel and the pressure on the window when the vessel is full of water.

11. A water-tight box 12 cm. long, 6 cm. wide, and 3 cm. thick is filled with water. Compute the pressure upon it when it lies (*a*) upon its side, (*b*) upon its edge, (*c*) upon its end.

12. One leaf of a lock gate is 12 ft. wide and 10 ft. high. Compute the pressure on (*a*) the upper half, (*b*) the lower half, when the lock is full of water.

13. Suppose a tube 12 m. high to be inserted in the top of a water-tight cubical box containing 1 cu. m. What will be the pressure on the bottom, sides, and top of the box when the tube is filled with water? What is the total pressure tending to burst the box?

14. A bottle is lowered into a lake to a depth of 150 ft. What is the pressure upon the end of the cork, which is 1.2 in. in diameter?

15. The water gauge in the water supply for a village registers 64 lb. per square inch. How high is the reservoir?

16. A dam 40 ft. long and 15 ft. high holds back the water of a lake. What pressure must it bear? Does the extent of the lake make any difference with the amount of this pressure?

17. Where is the center of pressure on the face of a dam 12 ft. long and 8 ft. high?

18. Suppose the staves of a barrel 3 ft. high, filled with water, are to be held in place by a single hoop. Where should it be placed?

19. If the disk in Fig. 121 is 8 cm. in diameter, what will be the upward pressure of the water upon it when it is 15 cm. below the surface of the water in the jar?

20. A wooden rod 4 cm. in diameter and 75 cm. long is thrust vertically into water its full length. How much force is required to keep it in place if the rod weighs 350 g.?

21. A pyramid 16 cm. high, having a base 24 cm. square, is just submerged in water. What is the pressure upon each of the triangular sides? What is the upward pressure upon the base?

LABORATORY WORK

1. Have a water-tight wooden box made, and bore holes 1 in. in diameter, as *A*, *E*, *C*, etc. (Fig. 122), in the sides and ends. In one of these, as *A*, insert a rubber stopper with a single hole. Cover the other holes with disks of thin rubber, and fasten them on water-tight by nailing around each of them a leather ring 1 in. in diameter on the inside. Fill the box with water and notice the effect of the gravity of the water. Thrust a glass rod through the hole in the rubber stopper and push it down to different depths. Observe the effect upon each diaphragm. An approximate measurement of this effect can be made by using a little rest and scale like that shown in Fig. 123.

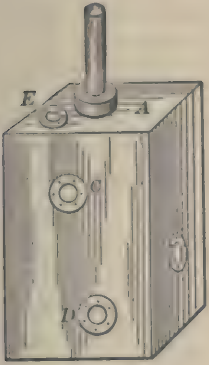

FIG. 122

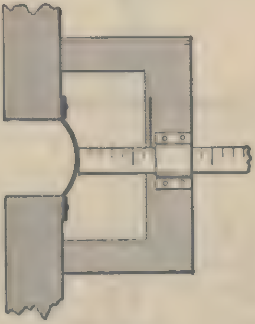

FIG. 123

2. Turn two wooden disks, such as are shown in Fig. 124 at *A* and *B*, and connect them by a dowel-pin rod *C*, about 2 ft. long. Slip over the disk *A* a tube of flexible rubber, — a piece of the inner tube of an old bicycle tire will do, — and fasten it water-tight to *A* and *B* by leather bands. Fill it with water and measure the divergence of the walls of the tube from a vertical line. Does the pressure increase proportionally to the depth?

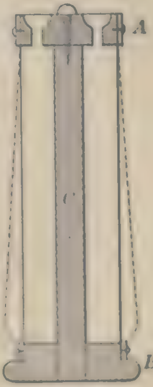

FIG. 124

3. Place in the bottom of a shallow pan a piece of smooth glass, and stand upon it a heavy lamp chimney of the form shown in Fig. 125, with the ends ground smooth. Pour water into the chimney, and observe what takes place when it rises to some height, as *A*. Explain. Set the chimney upon the small end and pour in water. Explain the different results.

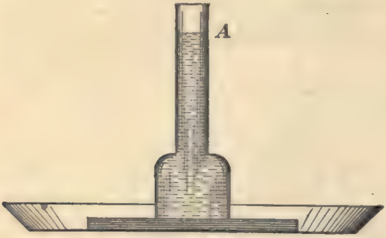

Fig. 125

III. Specific Gravity

143. The Principle of Archimedes. — Experiment 53. — Tie a strong thread to a stone, suspend the stone from a spring scale, and note its weight. Weigh again, letting the stone hang in a beaker of water, and it will be found to weigh less. Why?

Experiment 54. — Suspend from one side of a balance a short brass tube *A* (Fig. 126), and from a hook in the closed bottom of this tube suspend a solid cylinder *B*, which will just fill the tube. Put weights upon the other scale pan until the beam is horizontal. Immerse *B* in water, and the equilibrium will be destroyed. Fill *A* with water, and the equilibrium will be restored.

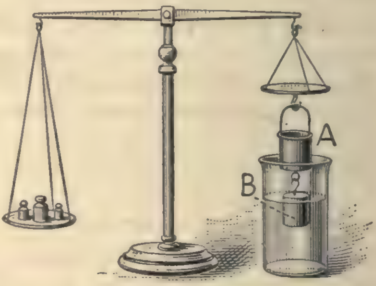

Fig. 126

We learn from the above, both that a body appears to lose weight when it is immersed in a liquid, and that the amount of this loss is exactly the weight of the water displaced. This *Principle of Archimedes* may be stated as follows:

A body immersed in a liquid loses as much in weight as the weight of the liquid displaced by it.

This tendency of a liquid to lift a submerged body is called its *buoyant force* or *buoyancy*, and depends in amount upon the density of the liquid and the size of the body.

If a body, a cube for instance, is immersed in a liquid, the horizontal pressure acting upon any side will be exactly counterbalanced by the pressure upon the opposite side. The downward pressure upon the upper surface *C* will be equal to the weight of a column of water having for its base the area of *C*, and for its height the depth of *C* below the surface of the water. The upward pressure upon the lower surface *D* will be equal to the weight of a column of water having for its base the area of *D*, and for its height the depth of *D* below the surface of the water. The difference between these pressures is the buoyant force of the liquid, and is equal to the weight of a quantity of the liquid that has the same volume as the submerged cube. This conclusion is verified by the result of Experiment 54.

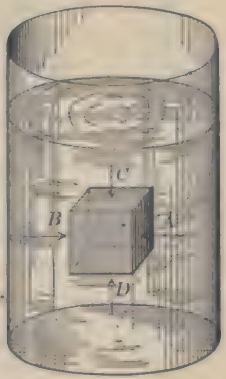

Fig. 127

144. Floating Bodies. — When bodies are placed in a liquid, the position they finally take will be dependent upon the relative densities of the body and the liquid. If a stone is placed in water, since it is heavier than the water, it will sink. If a drop of olive oil is placed in a mixture of alcohol and water, of the same density as itself, it will remain wherever it is placed. If a piece of wood is placed in water, it will rise to the surface and float. The principle of Archimedes applies to each case, however, and we may write this *Law of Floating Bodies:*

A floating body will displace a volume of liquid whose weight equals its own.

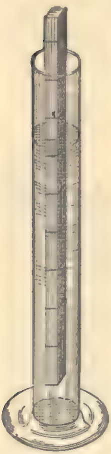

FIG. 128

EXPERIMENT 55. — Make a bar of pine wood 25 cm. long and 1 cm. square. Bore a hole in one end and run in molten lead. Divide off one side of the bar into centimeters. Cover the bar with melted paraffin, melting it into the pores of the wood over a flame. Float the bar upright in a tall jar (Fig. 128); then, since 1 c.c. of water weighs 1 g., the reading of the height at which it floats will give the approximate weight of the bar in grams.

145. Density. — The quantity of matter, or the mass, in a unit volume is called the density of a substance. If we assume the quantity of matter in 1 c.c. of pure water as our unit, its density will be 1, and the quantities of matter in the same volumes of other substances will be their *relative densities.* The density of a body is found by dividing its mass by its volume. If a piece of lead, for example, has a mass of 45.4 g. and a volume of 4 c.c., then its density equals $45.4 \div 4 = 11.35$ g. per cubic centimeter.

146. Specific Gravity. — Since the ratio between the weights of equal volumes of substances in the same place is the same as the ratio of their masses, we can use the term *specific gravity* in place of *relative density.* Since, also, pure water is taken as the standard in specific gravity, we may express it by the following formula:

$$\text{Sp. gr.} = \frac{\text{weight of the body in air}}{\text{weight of an equal volume of water}},$$

or

$$\text{Sp. gr.} = \frac{\text{weight of the body in air}}{\text{loss of weight in water}},$$

or

$$\text{Sp. gr.} = \frac{W}{W - W'}. \qquad (38)$$

In this expression W is the weight of the body in air, and W' its weight in water.

147. To find the Specific Gravity of a Body Heavier than Water. — Tie a light cord about the body, suspend it from one arm of a balance, and weigh it; call this weight W. Weigh again with the body suspended in water, as in Fig. 129. Call this weight W'. Substitute these values in Formula 38, and the result will be the specific gravity of the body.

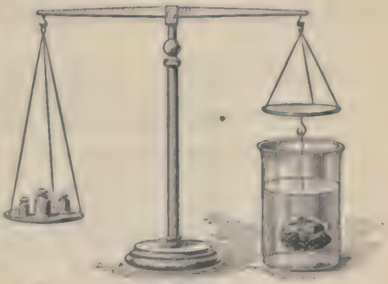

FIG. 129

EXAMPLE. — The weight of a stone in air (W) = 146 g.
Its weight in water (W') = 94 g.

$$\therefore \text{Sp. gr.} = \frac{146}{146 - 94} = \frac{146}{52} = 2.8.$$

148. To find the Specific Gravity of a Body Soluble in Water. — Weigh the body in air (W), and then in some liquid in which it does not dissolve (W'). Find the specific gravity $\left(\frac{W}{W - W'}\right)$ with reference to the liquid, and then multiply by the specific gravity (s) of the liquid used with reference to water.

EXAMPLE. — The weight of the body in air (W) = 214 g.
Its weight in the given liquid (W') = 143 g.
The specific gravity of the liquid (s) = .915.

Then $$\text{Sp. gr.} = \frac{Ws}{W - W'} = \frac{214 \times .915}{214 - 143} = 2.76.$$

149. To find the Specific Gravity of a Body Lighter than Water. — Weigh the body in air (W), then weigh a heavy sinker both in air and in water, and call its loss of weight l. Tie the sinker to the body and find the loss of weight of the two in water l'. From the loss of the two subtract the loss of the sinker, and the result will be the loss of the light body. Divide its weight in air by this difference, and the result is the specific gravity.

Example. — Weight of body in air $(W) = 23$ g.
Weight of sinker in air $(s) = 231$ g.
Weight of sinker in water $(s') = 199$ g.
Weight of body and sinker in air $(W + s) = 254$ g.
Weight of body and sinker in water $= 166$ g.
Loss of body and sinker in water $(l') = 88$ g.
Loss of sinker in water $(s - s') = l = 32$ g.

$$\text{Sp. gr.} = \frac{W}{l' - l} = \frac{23}{88 - 32} = .41.$$

150. To find the Specific Gravity of Liquids. — (*a*) *By the Specific Gravity Bottle.* — Any bottle with a small neck having a fixed mark around the neck can be used in this method. Weigh the bottle when empty (a). Fill with water to the fixed mark and weigh (b). The difference gives the weight of water $(b - a)$. Fill with the required liquid and weigh (c). The difference $(c - a)$ gives the weight of the same volume of the liquid. Then the specific gravity will be $\frac{c - a}{b - a}$.

Note. — Since the density of water depends upon both its purity and temperature, in order to get accurate results, distilled water at a temperature of 4° C. must be used. The temperature 4° C. is chosen because water has its greatest density at that temperature.

Example. — Weight of the empty bottle $(a) = 54$ g.
Weight of the bottle filled with water $(b) = 304$ g.
Weight of the bottle filled with the liquid $(c) = 252.25$ g.

$$\text{Sp. gr.} = \frac{c - a}{b - a} = \frac{252.25 - 54}{304 - 54} = \frac{198.25}{250} = .793.$$

Specific gravity bottles are usually made to hold a certain number of grams of water at a stated temperature, and are so marked.

If the bottle holds 1000 g. of water, the specific gravity can be obtained directly. For example, if a thousand-gram bottle holds 1240 g. of hydrochloric acid, then its specific gravity is 1.240.

(*b*) *By the Specific Gravity Bulb.* — Weigh some heavy body in air (a), then in water (b), and then in the liquid (c); then will the specific gravity of the liquid be $\frac{a-c}{a-b}$.

Example. — A brass ball weighs 463 g. in air (a), 407.77 g. in water (b), and 416.83 g. in petroleum (c); hence,

$$\text{Sp. gr. of petroleum} = \frac{463 - 416.83}{463 - 407.77} = \frac{46.17}{55.23} = .836.$$

(*c*) *By the Hydrometer.* — A hydrometer usually consists of a small glass-tube to which two larger bulbs are sealed. Either mercury or small shot are put into the lower bulb in order to keep the stem of the instrument vertical. For liquids heavier than water the unit mark is placed at the upper end of the stem, which is graduated decimally. This instrument, which is a constant weight hydrometer (Fig. 130), is used by placing it in the liquid in a hydrometer jar, and reading the height to which the liquid stands on the stem. Special forms of hydrometers are used for special liquids. The *alcoholmeter* is used for determining the per cent of absolute alcohol in spirits, and the *lactometer* for testing the purity of milk.

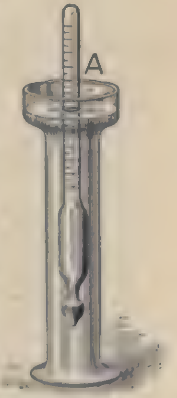

Fig. 130

PRACTICAL QUESTIONS AND PROBLEMS

1. When a bucket is filled by immersing it in water, why is it so much harder to lift the bucket out of the water than when it is below the surface?

2. Will a flat sheet of tin float on water? Why? Can it be bent into such a shape that it will float? Why?

3. A stone, the volume of which is 2 cu. ft., weighs 225 lb. in water. (*a*) What will it weigh in the air? (*b*) What is its specific gravity?

4. A piece of marble weighing 426 g. in air weighs only 276 g. in water. (*a*) What is its specific gravity? (*b*) What is its volume?

5. A body 25 cm. long, 12 cm. wide, and 6 cm. high, is suspended with its under side horizontal and 44 cm. below the surface of the water. What is the pressure on each face, and in what direction? What is the effect of these pressures?

6. If a pole 8 or 10 ft. long is plunged vertically into a deep pool, it is thrown out for half its length. Why?

7. 5.6 cu. ft. of a certain metal weighs 4000 lb. What is the specific gravity of the metal?

8. A specimen of glass weighed 321 g. in air, and 224.6 g. in water. What is the weight of a plate 3 m. long, 2.5 m. wide, and 1.5 cm. thick?

9. Find the weight of a block of marble (sp. gr. = 2.837) 6 ft. long, 4 ft. wide, and 3 ft. thick. How much work must be done to raise it 125 ft. vertically?

10. Find the weight of an ivory ball (sp. gr. = 1.917) 4 cm. in diameter.

11. Find the weight of a steel shaft 5.5 ft. long and 5 in. in diameter. (Sp. gr. = 7.82.)

12. A certain body weighs 437 g. in air, and 202.7 g. in a liquid, the specific gravity of which is 1.42. What is the specific gravity of the body?

13. Compute the specific gravity of paraffin from the following data: Weight of paraffin in air, 138 g.; weight of sinker, 210 g.; weight of sinker in water, 191.5 g.; weight of both in water, 171.61 g.

14. A specific gravity bottle which weighs 231 g. weighs 481 g. when filled to a certain mark with water, and 691.25 g. when filled with sulphuric acid. What is the specific gravity of the acid?

15. A piece of rock crystal weighing 14.326 g. in air, weighed 8.926 g. in water and 6.658 g. in nitric acid. What was the specific gravity of the acid?

16. How much would a platinum ball 3 cm. in diameter (sp. gr. = 20.337) weigh in mercury (sp. gr. $\doteq$ 13.6)?

17. What must be the volume of a hollow brass ball weighing 2.5 kg. that it may just float in water? What is its diameter?

18. A cast iron ball (sp. gr. = 7.1) 6 in. in diameter floats upon mercury. What part of its volume is above the surface?

19. The composition of a number of alloys is given below. Compute the specific gravity of each. A table giving the specific gravities of the metals used may be found in the Appendix.

Red brass. Copper 90 parts, zinc 10 parts.
Yellow brass. Copper 70 parts, zinc 30 parts.
Bronze. Copper 85 parts, tin 15 parts.
German silver. Copper 52 parts, zinc 26 parts, nickel 22 parts.

LABORATORY WORK

1. Measure the diameter of a ball that will sink in water. Take a number of measurements, and take their average for the diameter. Compute its volume. Weigh it. Pour water into a cylinder graduated in cubic centimeters. Read the level of the water. Fasten a thread to the ball and suspend it in the water in the cylinder. Read again. How does the difference in the readings compare with the computed volume? Weigh as many cubic centimeters of water as are equal to the volume of the ball. Find the specific gravity of the ball by Formula 38.

2. Find, by the method of weighing, the specific gravity of a quartz crystal; a piece of cast iron; a piece of glass tubing; a silver dollar.

3. Find the specific gravity of a piece of wax or paraffin, using a lead ball for a sinker.

4. Find the specific gravity of the same piece by the use of the Nicholson hydrometer, shown in Fig. 131. This is made of a brass tube at the bottom of which is a cone-shaped vessel, which is loaded so that the hydrometer will stand with the upper end about an inch above the surface of the water. At the upper end is a vertical wire which supports a brass plate for weights.

This is a hydrometer of constant volume, and the reference mark is placed at *A* on the wire. Find the specific gravity as follows:

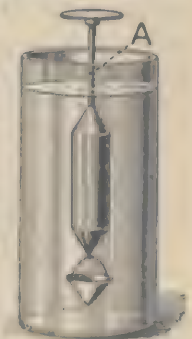

FIG. 131

Put weights in the upper pan, until the mark A is at the surface of the water. Call this weight W. Remove the weights and put on the piece of wax. Add weights until the mark A is again at the surface. Call this weight W'. Again remove the weights. Tie the wax to the lower pan with a piece of thread and add weights until the mark A is brought to the surface. Call this weight W''. Then

$$\text{Sp. gr.} = \frac{W - W'}{W'' - W'}. \quad \text{Why?}$$

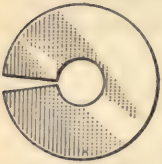

Fig. 132

A disk cut as in Fig. 132 is convenient to put over the top of the jar below the upper pan, as it prevents the pan from going into the water if too heavy weights are put on, and also prevents the weights from falling into the water.

5. Determine the specific gravity of alcohol with the specific gravity bottle.

6. Make a specific gravity bulb by closing one end of a glass tube with thick walls, and drawing out the other end as shown in Fig. 133. Use this to determine the specific gravity of the alcohol used in No. 5. Keep a record of the weight of the bulb in air and its loss of weight in water.

7. Make a 2 % solution of common salt and measure its specific gravity with a hydrometer. Add enough salt to make a 4 % solution and again take the specific gravity. Keep adding salt enough to increase the per cent of the solution by 2 each time, and take corresponding hydrometer readings. Take these readings until the solution is saturated, being sure that all the salt is dissolved each time. Tabulate your results, and from them draw a curve, laying off the percentages on the axis of X and the hydrometer readings on the axis of Y. Study this curve carefully and interpret it.

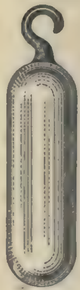

Fig. 133

8. Select a piece of glass tubing from 4 to 6 ft. long, and heat the middle of it in the flame of a broad fish-tail burner. When it is cherry red take it from the flame and gently bend it until the arms are parallel. This makes a more even bend than is made by using the Bunsen flame. Pour a little mercury into the tube and let it come to a level, AB (Fig. 134). Pour water into one arm and enough alcohol into the other to keep the mercury at the level AB. Read the height of the water column AC and that of the alcohol column BD; then will the specific gravity of the alcohol be expressed by the following formula:

$$\text{Sp. gr.} = \frac{AC}{BD}.$$

This method is called the *method of balancing columns.* If the liquids do not mix, the mercury can be dispensed with, but in most cases it is preferable to use the mercury. The reading of the columns can best be done by placing a meter stick between the columns and using a reading telescope with cross hairs.

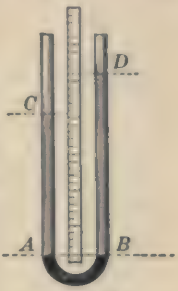

FIG. 134

9. Select two pieces of glass tubing about a meter in length, and having an internal diameter of 5 or 6 mm. Connect them at one end with a T-tube by short rubber tubes, PP (Fig. 135). Fasten them to a suitable support and provide two cups, C and D, into which the lower ends of the tubes project. Place water in C, and the liquid of which the specific gravity is wanted in D; then, by suction upon a flexible rubber tube connected with the upper end of the T-tube E, draw the air from A and B. The liquids will at once rise and stand at heights that are inversely proportional to their densities. Put a clamp upon the rubber tube to close it air-tight, and read the heights of columns A and B; then, as before, Sp. gr. $= \frac{AC}{BD}$.

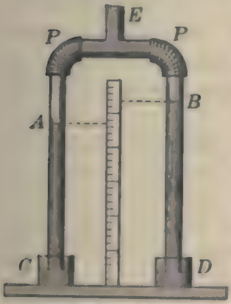

FIG. 135

NOTE. — Wet the rubber tubes on the inside with glycerin, and wind the rubber to the glass tubes with cord or wire. Read on a line tangent to the meniscus, using a reading telescope if possible, and allow for the capillarity of the liquids, which can be read before suction is applied.

This method is called the *method of Hare's apparatus.*

10. Wind 25 ft. of spring brass wire No. 24 into a close coil over a rod about ¾ in. in diameter. Suspend this at one end, and from the

other end suspend two scale pans made from watch crystals, as in Fig. 136. Provide a shelf that can be raised and lowered and fixed in any position, and place a glass of water upon it directly beneath the lower scale pan. Back of the spring place a long, narrow strip of mirror that has a millimeter scale laid off on the mercury side by fine cuts with the point of a knife through the mercury. Between the lower end of the spring and the upper scale pan thread a glass bead on the wire, and use the upper edge of this to measure from. Take the readings by looking across the top of the bead to the top of its reflection in the mirror.

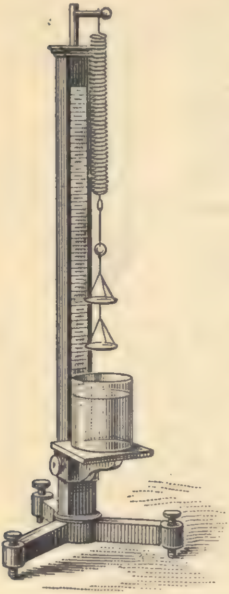

FIG. 136

Read the scale with no load, keeping the lower pan always in the water at such a depth that the water surface meets the single wire at a point above that at which the three supporting wires are connected.

Put 1 g. on the upper scale pan and read. Put 2 g. on and read. Put 3 g. on and read. Are the differences uniform? How many millimeters correspond to 1 g.? Weigh 6 in. of No. 24 brass wire.

Find the specific gravity of a small crystal as follows: Read first with no load, and call the reading W. Put the crystal in the upper pan and read, changing the position of the shelf to bring the water surface in the right place. Call this reading W'. Place the crystal in the lower pan and read. Call this W''. Then the specific gravity will equal $\frac{W' - W}{W' - W''}$. Why?

The above instrument is called the *Jolly balance*, and is in common use in determining the specific gravity of minerals by means of small specimens. It is a most accurate instrument if properly used, and the student should become perfectly familiar with its use, both for weighing in small quantities and for determining specific gravities.

CHAPTER V

GASES

151. Gases and Vapors. — A *gas* is matter in such a condition that it has a tendency to expand indefinitely. Gases have no independent shape, but take the form of the vessel in which they are confined. Great pressure and a low temperature are required to change gases into the liquid state. The name *vapor* is given to gaseous matter that is liquid or solid at normal temperatures. Water vapor is an example of vapor, while atmospheric air is a familiar form of gas, and will be used in studying the phenomena and properties of gases.

152. Expansibility. — Experiment 56. — Put a rubber bag — a toy balloon will answer — under the receiver of an air pump, having first blown a little air into it and tied the stem. Exhaust the air, and the balloon will be seen to increase in size. It will do this as long as the air is pumped from the receiver.

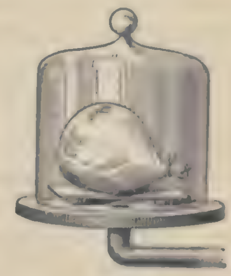

Fig. 137

In order to explain this expansion of the air, we shall need to understand the *kinetic theory of gases.* This theory considers that the molecules of a gas are in a state of rapid motion in straight lines, and that they continue to move in their paths until turned aside by striking either other molecules or the side of the containing vessel. When the balloon is put under the receiver of the air pump, the number of molecules of air per cubic centimeter is the same inside of it as outside of it, and the bombardment of the molecules on one side neutralizes that on the other, and the walls of the bag are loose. As soon as air is taken from the receiver, however, the number of molecular blows on the inside exceeds the number on the outside for the same surface, and the bag is stretched out until they are equal. This means that there are again the same number of molecules in the same space both inside and outside, or, the density is the same. If now the air is let into the receiver, the blows on the outside increase and the bag shrinks to its original size, beaten down by the impact of the molecules of the outside air.

153. Compressibility. — In order to show the compressibility of gases, it is only necessary to apply force to an air-tight piston moving in a cylinder closed at one end. It can be shown in a very simple way by pushing the open end of a long test tube below the surface of water, when it will be found that the deeper it is thrust into the water, the higher the water rises within it; and the more the air is compressed, the greater is the pressure required to force the test tube into the water.

154. Elasticity. — Gases are not only compressible, but they are perfectly elastic, as may be illustrated in the following experiment:

EXPERIMENT 57. — Raise the piston of a bicycle pump to the top, then close the tube leading from the pump and force the piston down. A sharp push will bring it nearly to the bottom, showing a compression of, say, nine tenths. Now let the piston go, and it will rise again to the top of the pump.

The elasticity of gases differs from that of solids in that it is elasticity of *volume* and not of *form*.

155. Weight. — Though gases are the lightest forms of matter, each has its own weight, which may be obtained directly by weighing.

EXPERIMENT 58. — Weigh on a delicate balance a light glass flask that is fitted with a stopcock. Exhaust the air and weigh again, and the flask and contents will be found to be lighter than before.

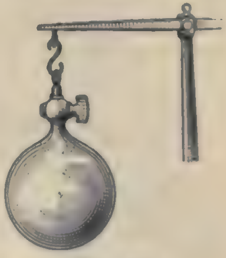
FIG. 138

By an extension of this method the weight of air and other gases has been found. The weight of 1 c.c. of dry air at 0° C., and the barometric pressure of 760 mm., is .001293 g. Since the weight of water under the same conditions is practically 1 g., the weight of air is $\frac{1}{773}$ of the weight of water. Hydrogen, the lightest known gas, weighs .0000895 g. per cubic centimeter; hence air is about 14.4 times as heavy as hydrogen. The weight of air in English measure is .31 grains per cubic inch, and of carbon dioxide .4725 grains.

156. Composition of the Atmosphere. — The air composing the atmosphere of the earth is a mixed gas. The kinds of gases and their average amount in volume are given in the following table ·

Nitrogen	77.50 parts
Oxygen	20.64 parts
Argon	1.00 parts
Carbon dioxide	.04 parts
Aqueous vapor	.82 parts
Total =	100 parts

Besides these are traces of other gases, as ammonia and ozone. The most recently discovered of the chief constituents is argon. This was discovered in 1895 by Lord Rayleigh and Professor Ramsey as the result of an admirable course of scientific research.

157. Pressure of the Atmosphere. — Since the molecules of gases move freely, it is evident that Pascal's Law will hold for gases as well as for liquids; and since air has weight, it is evident that the layers of air near the surface of the earth will be subject to a pressure due to the weight of the air above.

Experiment 59. — Tie a sheet of thin rubber over one end of a bladder glass and place it on the plate of an air pump. Remove a part of the air below the rubber by a stroke or two of the pump. The rubber will be pushed inside the glass. What supports the downward pressure of the air before the pump is worked?

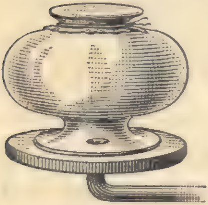

Fig. 139

This experiment can be varied by tying a piece of wet bladder over the top of the glass and letting it dry. On pumping out the air, the bladder will burst with the pressure.

Experiment 60. — Cut off the stem of a thistle tube about 4 in. from the cup. Slip over the stem a flexible rubber tube *B*, and in the other end of this tube put a short glass tube *C* for a mouthpiece. Tie a thin rubber sheet over the cup *A* and draw out some of the air by suction. Hold the cup in different positions and determine whether the air presses equally in all directions.

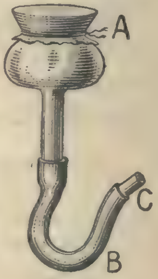

Fig. 140

Experiment 61. — Fill a tumbler full of water. Take a heavy card or a thin disk of ground glass and slide it over the top of the tumbler, being careful that no air bubbles are left below it. Hold the card while you invert the tumbler. Remove the support from the card, and it will remain. Why?

Hold the card on and turn the tumbler so that the card is vertical; when the hand is removed, the card still remains pressed against the tumbler, holding in the water. What does this show?

Experiment 62. — Select a long clear glass bottle and fit to the neck a rubber stopper with one hole. Pass through this a short glass tube with the inner end drawn down to a fine opening. Fit one end of a rubber tube to the outer end of the glass tube and connect the other end to the air pump. Exhaust the air. Pinch the tube together; hold the bottle as in Fig. 141, and pull the rubber from the glass tube when it is below the surface of the water in the dish *A*. The pressure of the air upon the surface of the water will force a stream through the tube, forming a fountain inside the bottle, and the water will continue to flow until the amount of water in the bottle is equal to the volume of air taken out.

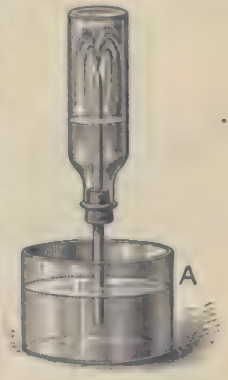

Fig. 141

This is a very old experiment called the *fountain in vacuo*.

158. Magdeburg Hemispheres. — An early form of apparatus for demonstrating the pressure of the atmosphere consists of two brass hemispheres with edges fitting airtight. Each hemisphere is fitted with a handle, and one of them has a stopcock by which it can be attached to an air pump. When the air has been exhausted, the hemispheres can be separated only by a pull that depends on the difference between the internal and external pressures.

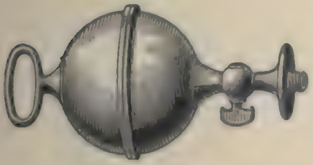

Fig. 142

159. Measurement of Atmospheric Pressure. — While the above experiments have demonstrated the existence of atmospheric pressure, they have given very little idea of its amount. The principle employed in finding its amount is the same as that of balancing columns used in finding the specific gravity of liquids. If a bottle is filled with water and inverted with its mouth under the surface, as in Fig. 143, the water will remain in the bottle. The downward pressure of water in the bottle *A* is counterbalanced by the downward pressure of the air upon the surface of the water in *B*, since the downward pressure upon the surface is transmitted into an upward pressure at the mouth of the bottle.

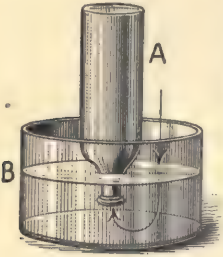

Fig. 143

In order to balance the entire pressure of the atmosphere by a water column, the bottle in Fig. 143 would need to be extended into a very long tube; but by using a liquid heavier than water, a correspondingly shorter tube can be used.

Experiment 63. — Procure a glass tube 80 cm. long and about 6 mm. in internal diameter, and close it at one end. Fill it nearly full with clean mercury. Close the open end with the finger, and invert several times to remove all air bubbles clinging to the sides of the tube. Now fill the tube full, put a finger over the open end, invert, and place the open end beneath the surface of mercury in a dish. Remove the finger carefully so that no air shall get into the tube. The mercury will fall, and the height at which it stands will measure the atmospheric pressure.

160. Atmospheric Pressure at Sea Level. — The average height at which the mercury column stands at the level of the sea is 76 cm., and this height is independent of the diameter of the tube. If the area of the cross section of the tube is 1 sq. cm., the volume of the mercury will be 76 c.c., and since its specific gravity is 13.596, its weight will be

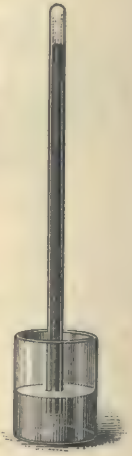

Fig. 144

1033.3 g. In English measure the average height of the column is 30 in., and if its cross section is 1 sq. in., its weight will be 14.7 lb. Since this weight is the measure of the pressure of the air, we can state the following:

The pressure of the atmosphere is 14.7 *lb. per square inch, or* 1033.3 *g. per square centimeter.* This is called a pressure of **1 Atmosphere**, and as it is constantly changing, it is called in round numbers 15 lb. per square inch, or 1 kg. per square centimeter.

161. The Barometer. — The experiment with the glass tube filled with mercury was first made by Torricelli in 1643, and the space above the mercury column in the tube is called a *Torricellian vacuum.*

The mercurial barometer consists essentially of a glass tube 34 *in. long, filled with mercury, and inverted with its lower end constantly below the surface of mercury in a cistern.* It is fixed in a vertical position with a scale graduated along the top near the end of the mercury column, the zero of this scale being the surface of the mercury in the cistern at the bottom (Fig. 145).

In reading the barometer a vernier scale is usually used to secure accuracy. The vernier must be brought to the top of the convex surface of the mercury, and the eye must be on a horizontal line from the top of the column; this may be secured by placing a small vertical mirror behind the top of the column, and placing the eye so that its image and the top of the column coincide. Before the height is read, the surface of the mercury in the cistern must

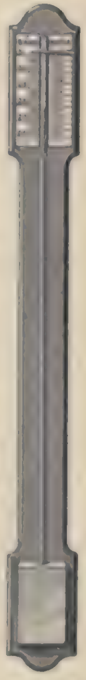

FIG. 145

be brought to the fixed zero. This is done by turning a screw which raises or lowers the mercury in the cistern until it just touches the point of a pin projecting downward from the frame of the instrument, as shown in Fig. 146.

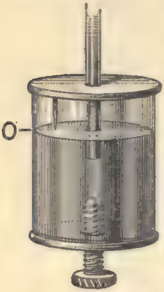

FIG. 146

If a liquid lighter than mercury is used, the column will be correspondingly longer, and changes in it, caused by changes in atmospheric pressure, will be correspondingly greater. The glycerin barometer has a height of about 27 ft., and a change of nearly 11 in. for every change of 1 in. in the mercury barometer.

162. The Aneroid Barometer consists essentially of a flat metal box, with circular cross section, one end of which is of very thin metal. The air is partly removed from this box, and the box is hermetically sealed. The thin face is then connected with a system of wheel work, so that its movements are indicated by a pointer moving around a graduated circular face. Why should the thin face have any movement?

The aneroid barometer is portable and very useful in measuring the heights of mountains.

163. Variation of the Barometer. — Since the height of the barometric column measures the pressure of the air, any cause that affects this pressure shows itself in changes in the barometric readings. A constant use of the barometer is made in the Weather Bureau in forecasting changes in the weather. As the result of observation for a series of years, the relation of barometric readings to the state of the weather may be stated as follows:

I. *A rising barometer precedes fair weather.*

II. *A falling barometer precedes foul weather.*

III. *A sudden fall in the barometer precedes a storm.*

IV. *An unchanging high barometer indicates settled fair weather.*

164. Cyclonic Storm Pressure. — The relation between the readings of the barometer and the direction of the wind in circular or cyclonic storms may be studied in connection with Fig. 147. At *O*, the center or eye of the storm, the pressure will be least; while at *A*, *B*, *C*, and *D* the pressure will be greater, and the air will rush toward *O*. If in the northern hemisphere, the wind from *A* (the north), in blowing toward *O*, will move into a part of the earth rotating toward the east more rapidly than itself, and so will fall behind and go to the west of the center. This is true of all the air to the north of *O*, while the reverse is the case in regard to all the air to the south of *O*. This gives to the storm a rotary motion in a counter-clockwise direction, and if one stands with his back to the wind, the storm center, or region of lowest barometer, will be on his left hand.

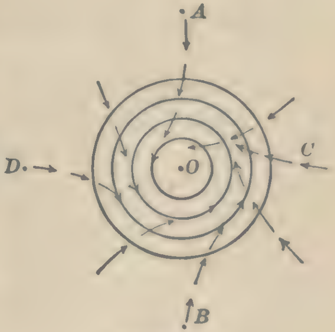

Fig. 147

165. Height of the Atmosphere. — The compressibility of the air is so great that the layer in contact with the surface of the earth is more dense than those above it. Though the density constantly decreases as the distance from the earth increases, no uniform rule can be given that will show the relation between barometric readings and the corresponding heights of the atmosphere. However, a fall of one inch in the mercury column, from the reading at sea level, indicates an elevation of about 900 ft.

If the air were of uniform density, we should have what is called the *homogeneous atmosphere*. Its height can be found by dividing the pressure upon a given area by the weight of a column of air having the given area for its base and 1 unit of length for its height; or, $H = \frac{P}{W}$. (39)

166. Boyle's Law. — The relation between the volume of a gas and the pressure that it sustains was investigated independently by two physicists, Boyle and Mariotte. The results obtained were formulated in what is called *Boyle's Law*, which may be stated as follows:

The temperature remaining the same, the volume of a given mass of gas varies inversely as the pressure acting upon it. This may be expressed by the proportion $V : V' = P' : P$, from which we get

$$VP = V'P', \qquad (40)$$

$$i.e.\ VP = \text{a constant quantity.}$$

The mass of the air remaining the same, it is evident that the density must increase as the volume diminishes; hence,

For the same temperature the density of a gas is directly proportional to the pressure acting upon it.

167. Verification of Boyle's Law. — (*a*) *For Pressures Greater than One Atmosphere.* — Experiment 64. — Bend a glass tube as shown in Fig. 148, the long arm being open and the short one closed. Fix this to a vertical support and place a graduated scale between the two arms. Pour mercury into the long arm by means of a long funnel, and tip the tube in such a way as to let bubbles of air pass from the short tube into the long one, and thus bring the mercury to the same level AB in both. This line is chosen at a convenient position, say 20 cm., below the closed end. On pouring mercury into the long tube it will be found necessary to fill it to a height of about 760 mm. above the mercury in the short tube to reduce the volume of the gas one half. The pressure upon the mercury in the short tube is the elastic force of the air above it, and this is equal to the pressure above the line CD in the long tube, which is two atmospheres, one being the 760 mm. of mercury and the other the free atmosphere above it. State how this proves the law.

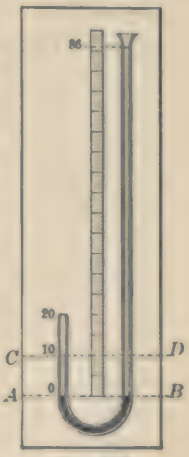

FIG. 148

(*b*) *For Pressures Less than One Atmosphere.* — EXPERIMENT 65. — Fix vertically a glass tube closed at the lower end, 70 cm. long and at least 8 cm. in internal diameter. Cut off a piece of glass tubing 6 or 7 mm. in external diameter and make three marks upon it, one at 10 cm., one at 20 cm., and one at 58 cm. from one end. Pour mercury into the large tube until, on thrusting the smaller tube into it with the 10 cm. mark uppermost, the mercury will rise to the 10 cm. mark. Place the finger over the top and inclose a column of air 10 cm. long. Now raise the smaller tube until the mercury sinks to the 20 cm. mark on the inside of the tube, and on the outside it will stand nearly at the 58 cm. mark. Why?

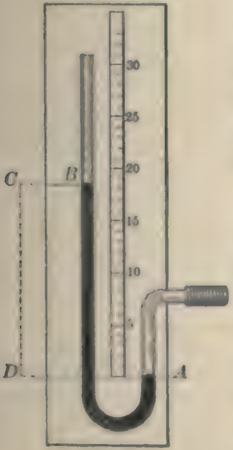

FIG. 149

168. The Manometer is an instrument for measuring the pressure of gases. It is made in two forms, the open and the closed.

(*a*) *The Open Manometer* consists of a bent glass tube held in a vertical position by a frame having a graduated scale between the two arms of the tube (Fig. 149). The short arm is attached to the vessel containing the gas after mercury or some other suitable liquid has been poured into the manometer. Before the gas is turned on, the liquid will stand at the same height in both arms, but as soon as the gas is turned on, the pressure is shown by the difference in the level of the columns. The weight of the column of liquid *CD* is the measure of the pressure in excess of 1 atmosphere.

(*b*) *The Closed Manometer* is shown in Fig. 150. It differs from the open manometer in being closed at one end and much shorter. Before the pressure is turned on, the mercury stands at the level *BD*. When the stopcock is turned, the pressure of the gas has not only to maintain the difference in the pressure of the mercury columns, but to compress the volume of air from *AB* to *AC*. This form is used when the pressure is great. It is also called a *pressure gauge*. Explain how to calculate pressure by its use.

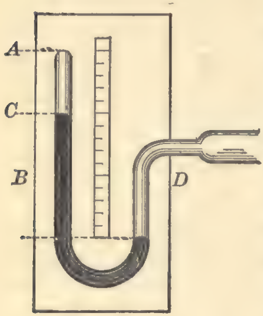

FIG. 150

169. The Siphon is a bent tube with arms of unequal length, used to transfer a liquid from one vessel to another at a lower level by carrying the liquid over the edge of the vessel. Any tube of proper shape can be used as a siphon, provided the liquid does not act chemically upon it. A flexible tube, like a rubber tube, makes a very convenient siphon.

EXPERIMENT 66. — Bend a glass tube as shown in Fig. 151. Fill it with water, and close the end of the long arm with the finger. Invert it and place the end of the short arm below the surface of water in a beaker. The water will at once begin to flow, and will continue until the water in the beaker is below the end of the tube.

170. Cause of the Action of the Siphon. — At the level of the water surface, *A* (Fig. 151), the upward pressure in the short arm of the siphon is the atmospheric pressure, while the downward pressure is the weight of the water column *AB*. The upward pressure at the point *D* is also the atmospheric pressure, and the downward pressure is the weight of the water column *DC*. The resulting pressure at any point will be the atmospheric pressure minus the pressure of the water column at that point, and as the column *CD* is longer than the column *AB*, the resulting upward pressure at *A* is greater than that at *D*, and the water is forced from *A* toward *D*.

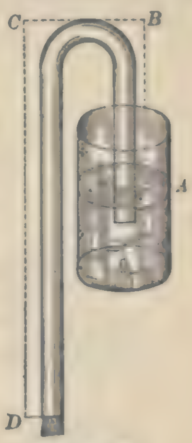

FIG. 151

It is evident that unless the pressure due to the liquid column *AB* is less than the pressure of the atmosphere, there will be no flow of the liquid. Hence a siphon cannot raise water more than 34 ft., nor mercury more than 30 in., when the barometer stands at the normal height.

The final resultant of the pressures depends upon the difference in the heights of the liquid columns; hence the greater the difference in height, the faster will be the flow.

171. The Air Pump is an instrument used for removing the air from any vessel with which it is connected. It consists of a cylinder *A* (Fig. 152), in which moves a piston *B*. This cylinder communicates by means of a tube *C* with a receiver *D*, from which the air is to be removed. There are two valves between the air in *D* and the external air: one in the base of the cylinder at *K*, and the other in the piston. These open outward, allowing the air to move in one direction only. At *G* there is a stopcock so arranged that it will either permit free passage for the air between the pump and the receiver, or cut it off altogether, or admit the external air to the receiver. *H* is an air-tight glass tube which communicates with the receiver, and contains a siphon barometer for measuring the degree of exhaustion.

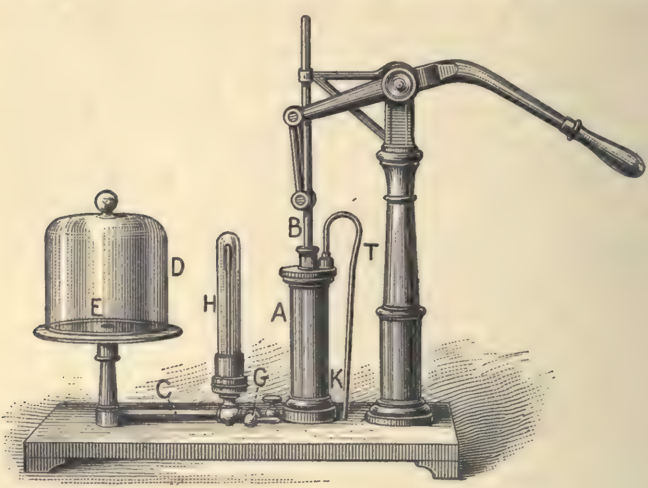

FIG. 152

172. Operation of the Pump. — Suppose the piston to be at the top of its stroke. The first movement downward will compress the air under it. This closes valve *K* and opens the valve in the piston. The air passes through this valve, and when the piston is at the bottom of its stroke, all the air in the cylinder is above it. As soon as the piston is raised, the air above it is condensed and the valve is closed, and as the piston rises, the air is forced out of a hole in the top of the cylinder, or through the small tube *T*. Each stroke is only a repetition of the first, except that the amount of air taken out diminishes with every stroke. Suppose the volume of the cylinder is $\frac{1}{9}$ of the volume of the receiver. The first stroke takes out $\frac{1}{10}$, the second $\frac{1}{10}$ of $\frac{9}{10}$, or $\frac{9}{100}$, etc.

173. Uses of the Air Pump. — There are many practical uses for the air pump, among them its application to vacuum pans for the making of sugar, in which the air is partly exhausted so that evaporation will take place at a lower temperature and the sugar will not be burned. Another important use is in making incandescent lamps.

Experiment 67. — Procure two small bottles and put into each the end of a U-tube fitting loosely in *A* (Fig. 153), and air-tight, through a rubber stopper in *B*. Fill *B* half full of water; place both under the receiver of an air pump and exhaust the air. At the first stroke, the water from *B* will begin to run into *A*. Explain.

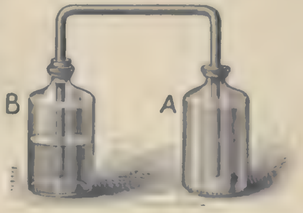

Fig. 153

Exhaust until all the water is drawn over, and then let air into the receiver. The water will run back into *B*. Explain.

Experiment 68. — Prepare a dry pine rod about 2 in. long and an inch in diameter. Fix a small wooden rod in one end and bore a quarter-inch hole in the other. Fill the hole nearly full of small shot and keep them in place by pouring wax over the hole. Put this in a beaker of water and vary the number of shot until the large rod will float just even with the surface of the water. Place the beaker and contents under the receiver of an air pump and exhaust the air. Air rises from the cylinder in bubbles. What does it show? Admit air to the receiver. Does the cylinder float at the same height as before? Explain.

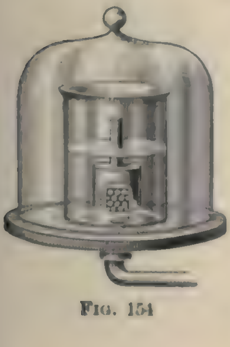

Fig. 154

174. Sprengel's Air Pump is a mercury pump, a simple form of which is shown in Fig. 155. The lower end of a straight glass tube is thrust below the surface of mercury in a cup, and the upper end is attached to a funnel for mercury. There is at *A* a stopcock to regulate the flow, and at *B* a side tube to which the vessel to be exhausted is attached. As the mercury falls down the tube, — which must be so small that a drop of mercury will fill it completely, — all the air below it is forced out the lower end. The air in *C* will expand and fill the tube between the first drop and the second, and this air will be driven out by the next drop. This is a slow method, but gives a good vacuum.

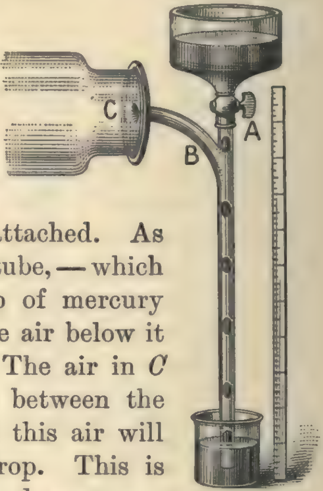

Fig. 155

175. The Condensing Pump. — If the valves in the pump shown in Fig. 152 were so arranged as to open downward instead of upward, the pump would be a condenser. This is the case in a simple condenser like the bicycle pump. It is frequently necessary, however, to transfer a gas from one vessel to another, as in filling cylinders for the limelight, and then an arrangement like that shown in Fig. 156 is used. The pipe *P* is attached to the gas supply, and the pipe *P′* to the cylinder in which the gas is to be compressed.

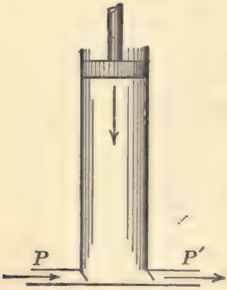

Fig. 156

Note. — It will be observed that the valves of pumps are shown diagrammatically, and simply represent the direction in which the gas flows.

176. The Suction Pump. — There is practically no difference between the air pump and the suction or lifting pump. In both the valves open upward and are air-tight. At the base of the cylinder a tube runs into the water supply, while near the top of the cylinder is a spout for carrying off the water. When the pump is first started, the air is pumped out, and the pressure of the atmosphere causes the water to rise in the tube *T* (Fig. 157) until it finally passes through the second valve, when it is lifted out. It will be seen that the upper valve must not be placed so that its lowest position shall be more than 34 ft. above the level of the water in the cistern. About 27 ft. is the practical limit.

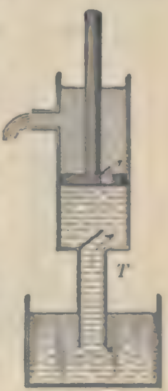

Fig. 157

177. The Force Pump. — The force pump is used in fire engines and hydraulic presses. Its principle is shown in Fig. 158. The piston has no valve, and fits air-tight. When the piston rises, the valve *V* opens and *V′* shuts. Water rushes in from the supply pipe *P*, forced by the pressure of the atmosphere. When the piston is pushed down, *V* closes, and *V′* opens, and the water is forced into the air chamber *A*, and from there out the delivery pipe *P′*. The elasticity of the air cushion in *A* forces the water out at *P′* in a steady stream, though it comes in through *V′* only during the downward stroke of the piston.

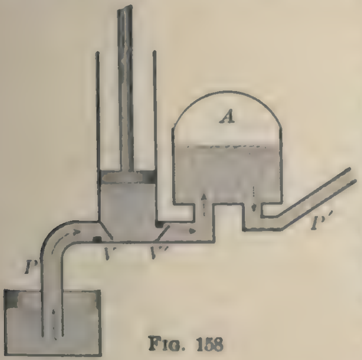

Fig. 158

178. Absorption of Gases by Solids. — Some porous solids have the property of absorbing gases to a great extent, a given body of the solid absorbing many times its own volume of the gas.

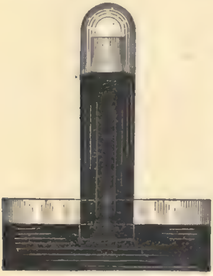

FIG. 159

EXPERIMENT 69. — Trim a piece of charcoal about an inch long so that it will slip easily into a large test tube. Invert the tube and fill it with ammonia gas. Pour mercury into a dish and place the piece of charcoal on its surface. Bring the test tube down over the charcoal and fix it in such a position that its mouth will be a little below the surface of the mercury. In a short time, the charcoal will absorb the ammonia, and the mercury will rise in the tube, as in Fig. 159. This property of charcoal is of value in the absorption of noxious gases.

179. Absorption of Gases by Liquids. — Liquids also absorb gases more or less freely. Water at normal pressure and temperature absorbs nearly twice its volume of carbon dioxide and more than a thousand times its volume of ammonia gas.

EXPERIMENT 70. — Fit two flasks with rubber stoppers, one having two holes and the other one. Draw out a glass tube to a jet and thrust it into the upper flask *A* (Fig. 160) after having filled *A* with ammonia gas. Thrust two tubes of the form shown in the figure through the other stopper. Fill the lower flask *B* nearly full, with a solution of litmus reddened with a few drops of acid. Press in the stopper and connect the two straight tubes with a short piece of rubber tubing having a clamp at *C*. Loosen *C* and force a little water into *A* by blowing through the pipe *D*, and the water will continue to flow until the flask *A* is nearly full. The quantity

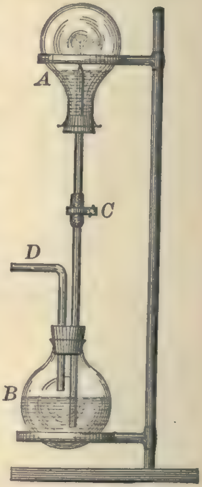

FIG. 160

of water that goes into *A* will measure roughly the gas absorbed. Notice the change in the color of the water in *A*.

180. Diffusion of Gases. — EXPERIMENT 71. — Fit a large rubber stopper with one hole into the open end of a porous cup, such as is used in small battery jars. Put one end of a glass tube about 2 ft. long through the stopper, and hold the tube inverted with the open end below the surface of water in a dish. Bring over the porous cup a jar filled with hydrogen, or with common illuminating gas, and bubbles will be seen to rush from the end of the tube and rise through the water, showing that the gas has passed into the cup. After the bubbles stop rising, remove the jar and notice what follows. What does this show?

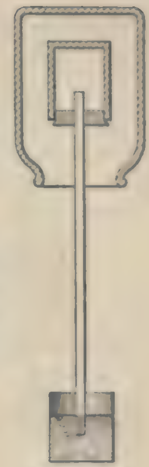

FIG. 161

PRACTICAL QUESTIONS AND PROBLEMS*

1. Suppose you put a rubber bag containing 160 c.c. of air under the receiver of an air pump and exhaust the air until the air in the bag has expanded to 240 c.c. What is the pressure under the receiver?

2. What would be the entire pressure on a pair of Magdeburg hemispheres 3 in. in diameter if the air inside could be entirely exhausted? How much of a pull would be required to separate them?

3. What is the atmospheric pressure on the end, side, and top of a box 4 ft. long, 3 ft. wide, and 2 ft. high?

4. What is the weight of air in a box 6 m. long, 3 m. wide, and 2.5 m. high?

5. When the barometer stands at 760 mm., at what height would sulphuric acid (sp. gr. = 1.841) stand in a barometric tube?

6. What is the pressure on each square centimeter when the mercury stands at 730 mm.?

7. To what volume must we compress a cubic foot of any gas to make its elastic force three times as great?

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* In all questions in which the pressure of the air must be taken into account, the barometer is understood to be at the normal height of 760 mm. or 30 in., unless otherwise stated.

8. The specific gravity of glycerin being 1.26, what will be the reading of a glycerin barometer when the mercury barometer reads 753 mm.? What change in the height of the glycerin column will correspond to a change of 1 mm. in the mercury column?

9. Assuming the exterior surface of a man's body to be 20 sq. ft., what is the entire pressure of the atmosphere upon it? Why is it not crushed by this weight?

10. Suppose that the air were as dense throughout its entire height as it is at the surface of the earth; what would be its height? What is such an atmosphere called?

11. If the closed arm of the U-tube used for verifying Boyle's Law is 20 in. above the zero line, how high must the mercury stand in the long tube to bring the mercury in the closed arm within 5 in. of the closed end?

12. If in Fig. 150 the distance *AB* is 12 cm., what pressure must be applied to bring the top of the mercury to within 4 cm. of *A*?

13. Over how great a height can water be carried in a siphon when the mercury stands 29.3 in. in the barometer?

14. Two siphons have the same cross section, but one carries water from a lake to a basin placed 10 ft. below its surface, and the other to one placed 16 ft. below. Will the water fill basins of equal size in the same time? Why?

15. Suppose you should put a barometer under the receiver of an air pump and gradually exhaust the air; how would it affect the height of the mercury? Why?

16. Show by a sketch how you would raise water by a lifting pump from a well 40 ft. deep.

17. If the capacity of the piston is one third that of the receiver, and we assume that the pump works without leakage, how much air remains after four upward strokes of the piston?

LABORATORY WORK

1. Calibrate a test tube by pouring into it 1 c.c. of water or mercury, and marking its height on the side of the tube, then a second, and so on until it is full. Fill this test tube nearly full of water and invert, putting the mouth of the tube into water in a beaker. Vary the quantity until you have exactly 2 c.c. of air in the top of the tube at *A*. Fix the tube in an upright position by pushing it through a hole in a card laid over the top of the beaker. Put the beaker and contents under the receiver of an air pump, and exhaust until the air occupies 4 c.c. How much air has been removed from the receiver? Exhaust until the air in the test tube stands at the 8 c.c. mark. How much air has been removed from the receiver? Let air into the receiver. What is the volume of the air in the test tube?

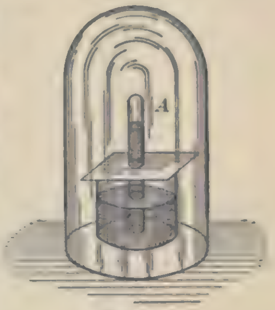


FIG. 162

2. Procure a glass tube about 1 in. in diameter and 2 ft. long. See that one end is cut off square, and round its edge in the flame of a Bunsen burner. Tie over this end a piece of thin sheet rubber. Fill the tube with water and invert, placing the open end under the surface of water. Observe the form taken by the rubber cap. Repeat the experiment with a similar tube of half the length. Prick either cap with a pin. What takes place?

3. Make a siphon barometer by closing one end of a glass tube, 1 m. long, in the flame of a Bunsen burner, and making a bend about 10 cm. from the open end. Fasten this to a vertical support, and fix a meter stick as in Fig. 163. Fill the tube with pure mercury, and place in position. Read and compare readings with your laboratory barometer.

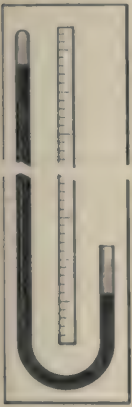


FIG. 163

4. Take a piece of glass tubing about 5 mm. in inside diameter and 1 m. long. Heat one end with a Bunsen burner, and when it is soft, work it out into the form of a funnel. Fit a short rubber tube with thick walls to the other end. Get a piece of similar tubing about 21 cm. long, and close one end as flat as possible. Fit a rubber tube to the open end of this, and attach both rubber tubes to a T-tube, as shown in Fig. 164. Wind all joints very firmly with strong cord or wire. Attach a short piece of rubber tubing to the third arm of the T-tube, and put on this a very strong clamp. Wire the tubes to a board, and place the board in a vertical position. Fix a meter stick along the side of the long tube, with its zero on a line drawn horizontally across the board 20 cm. from the closed end of the short tube, and fix part of a meter stick by the side of this tube. Pour mercury into the long tube, and bring it to the zero line in both branches, as in Experiment 64, removing any excess of mercury by loosening the clamp. Pour in a little mercury and take the readings of both columns. Keep adding mercury a little at a time until it stands nearly at the top of the long tube, taking readings after each addition. Tabulate these readings, and take a second set by drawing off at intervals a small quantity of mercury from the tube below, with readings after each drawing. From these readings make a curve to show the relation between the difference in heights of the mercury columns and the volume of the inclosed air, laying off heights on the axis of *X*, and volumes on the axis of *Y*.

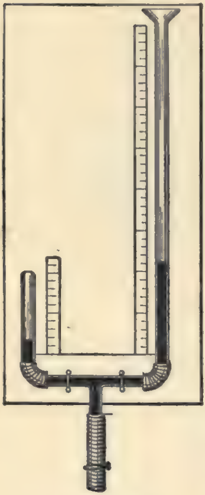


FIG. 164

5. Make three siphons of the same diameter, each having the short arm 4 in. long, but with the long arms 12, 18, and 24 in. respectively. Fill a jar nearly full of water. Hang the short arm of the first siphon over the edge of the jar, and set the water running; but carefully keep the water in the jar at the same height by pouring water gradually into it. Measure the water that runs out in one minute. Repeat this process with the other siphons, and find the relation between the difference in the lengths of the long arms, and the difference in quantities of water that flow out in the same time.

6. Close one end of a large-sized glass tube in the Bunsen flame. Draw the other end down to 1 cm. in diameter. Fit tightly over this a short piece of rubber tubing with thick walls. Put a clamp over the rubber tube, and carefully weigh the whole. Attach the tube to an air pump, and exhaust the air. Close the clamp, remove from the pump, and open the clamp under water. Take out, wipe dry, and weigh again. Fill the tube entirely full of water, and weigh. Determine the per cent of exhaustion.

CHAPTER VI

SOUND

I. WAVE MOTION AND VELOCITY

181. Sound Defined. — The physical definition of sound is any vibration that is capable of being perceived by the ear. The physiological definition includes also the effect produced upon the ear by such vibrations.

182. A Sounding Body is a Vibrating Body. — EXPERIMENT 72. — Hold a large jar, like the receiver of an air pump, horizontally by the knob, and draw a bow across the edge, or strike it lightly with a cork hammer. Is it a sounding body? Place a few carpet tacks inside the jar near the edge. Repeat the experiment. Is the jar in vibration?

EXPERIMENT 73. — Bore a hole in the top of a table and firmly set into it the handle of a tuning fork. Make a cork hammer by thrusting one end of a knitting needle through a large cork. Tie a shoe button to the end of a fine silk thread. Strike one prong of the fork with the hammer, and hold the button on the side of the fork near the top. Do its movements prove that the fork is a vibrating body? Why does not the button rebound to the same distance every time? Gradually lower it along the side. What is the effect? Hold the button between the prongs and observe.

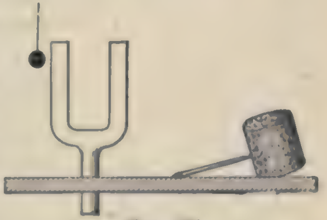


FIG. 165

Both these experiments prove that a sounding body is in vibration. An interesting way to show the vibration of a tuning fork is to set it in motion, and then bring it in contact with the surface of water upon which lycopodium powder has been scattered. The rapid blows of the prong will give rise to a beautiful set of waves.

183. The Transmission of Sound. — In order that the vibrations of the sounding body may be transmitted to the ear, the medium must be an elastic one. Gases, liquids, and solids transmit sound, but with varying intensities and velocities.

(*a*) *Gases.* — That gases transmit sound is a matter of universal experience, since the air is the common medium of sound transmission.

(*b*) *Liquids.* — Sound is transmitted by liquids more readily than by gases. If a person is swimming under water, he can hear with great distinctness the sound of two stones struck together under the surface.

(*c*) *Solids.* — A long wooden rod, a section of gas pipe, or the wires of a wire fence, can be used as a means of proving that solids are good conductors of sound. If an observer places his ear at one end of any of these, while the other end is scratched with a pin, the sound of the scratching is plainly heard through the solid body, though it may be entirely inaudible through the air.

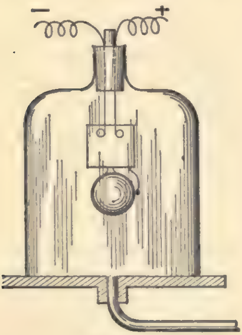


FIG. 166

184. Sound not Transmitted in a Vacuum. — EXPERIMENT 74. — Fit to an air pump receiver with a small neck a rubber stopper with one hole. Through this run two No. 30 insulated copper wires attached to an electric bell. Thrust a glass rod through the stopper to hold the wires in place and make the receiver air-tight. Exhaust the air and ring the bell by connecting the wires with a battery. Notice that the sound of the bell is very faint. Slowly admit the air, and notice how the sound increases in intensity.

185. Vibrations and Wave Motion. — A vibration is set up in a body when it moves over a certain path and then returns over the same path in an opposite direction, the action going on at regular intervals. The greatest distance reached from the position of rest is the *amplitude* of the vibration. The vibrations producing sound may be either *transverse*, *longitudinal*, or *torsional:* transverse, when the vibration is perpendicular to the length or axis of the vibrating body; longitudinal, when in the direction of its length; and torsional, when in a circular direction around the axis of the body.

EXPERIMENT 75. — Fill a rubber tube about 3 ft. long with fine sand. Tie a weight to one end, and suspend the other from a support. Take the tube by the middle, pull it to one side, and then let it go. This will give rise to a *transverse* vibration of the tube.

EXPERIMENT 76. — Remove the sand from the tube, and suspend as before. Pull the weight down several inches and release. It will rise and fall with a motion showing a *longitudinal* vibration.

EXPERIMENT 77. — Take hold of the weight and turn it around, twisting the tube somewhat. Release it and the weight will rotate, giving rise to a *torsional* vibration.

Water waves of small amplitude are, as a whole, similar to those produced by transverse vibrations in a stretched cord. The particles of the water, however, move in small circles or ellipses while the wave moves onward. This can be observed by watching the motion of a boat at a distance from the shore: the boat rises and falls with the waves, but does not advance with them. Near the shore the velocity of the wave below the surface is retarded by the sloping bottom and the outgoing water, so that the top of the wave curls over, forming a breaker.

186. Wave Length. — One particle of a vibrating body is in the same *phase* as another particle when it is moving in the same direction with the same velocity at the same time.

Fig. 167 shows the form of a wave, due to transverse vibrations, moving from left to right. The particle *A* is moving downward with a certain velocity, and the next particle that is in the same phase is *E*. The particle *C* has the same velocity, but is moving upward. The distance between particles in the same phase, measured in the direction of wave motion, as *AE*, is the *wave length.* The top of the wave at *B* is called the *crest*, while the bottom at *D* is the *trough.* The vertical distance from *B* to the horizontal line is the *amplitude.* This movement of a particle from crest to trough and back again in regular succession constitutes *simple harmonic motion*, a motion common to vibrations that give rise to sound. It is a simple matter to make a body record its own vibrations and show a wave form similar to Fig. 167.

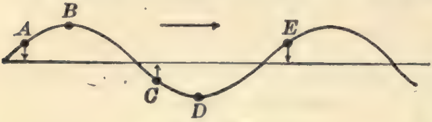


FIG. 167.

EXPERIMENT 78. — Bore a hole near the end of a long piece of whalebone, and fasten it by a screw to the side of a block screwed to a board. Black one side of a strip of glass by the smoke of a candle or of a piece of birch bark. Place it on the board between two guides and underneath the whalebone. Fix a bristle to the whalebone near the end so that it will just touch the glass. Vibrate the whalebone, and the bristle will make in the lampblack a nearly straight line twice the length of the amplitude. Vibrate again, and raise

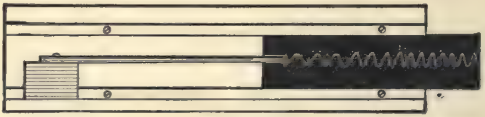


FIG. 168.

one end of the board so that the glass will slide out, and the vibrations will trace themselves in a beautiful wave form, as shown in Fig. 168.

The form of wave due to transverse vibrations can also be shown as follows:

EXPERIMENT 79. — Obtain a coil of spring brass wire a half inch in diameter and 10 or 12 ft. long. Hook one end to a screw eye in a post, and taking the other end in the hand draw the spring until it is stretched somewhat. Throw the coil into vibrations as a whole by a slight movement of the hand. Quicken the movement, and it can be thrown into vibrations in halves, thirds, quarters, etc., giving a number of complete waves.

When the spring is vibrating, as shown in Fig. 169, the points of no vibration are called *nodes*, as *N*, *N′*, while the points of maximum vibration, as *L*, *L′*, etc., are called *loops*. Whenever the wave starting from *A* tends to give a certain velocity to any particle, and the reflected wave from *B* tends to give it an equal velocity in the opposite direction, the two forces neutralize each other, the particle remains at rest, and a node is formed.

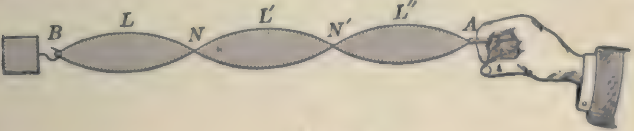


FIG. 169

NOTE. — This spring can be wound on a half-inch gas pipe fixed to turn in a lathe. If the spring cannot be obtained, make the experiment with a soft cotton clothesline.

187. Wave Motion in Air. — While the transmission of sound is by means of waves, the air does not vibrate transversely like the coil above, but longitudinally. The molecules that are put in motion by the forward movement of a sounding body, are suddenly pushed ahead of it; but their path is not long, since they strike other molecules which in turn set the molecules next to them in motion. When the sounding body moves back it tends to create a vacuum behind it, and the molecules we have been considering rush in to fill it. This sets up the to-and-fro motion of the air that constitutes a wave of sound.

Experiment 80. — Hook one end of the wire spring used in Experiment 79 as before, and stretch the spring somewhat by pulling on the other end. Put a knife blade between two of the turns of wire and draw it toward the end held by the hand, pushing a few of the coils together. Remove the knife suddenly, and the wave will run the length of the spring and be reflected by the hook back to the hand. By tying a piece of thread to the spring at the middle the longitudinal vibrations will be shown by the sudden, jerking, to-and-fro motion of the thread.

188. Condensations and Rarefactions. — Since the vibration of the air in a sound wave is a simple harmonic motion, the movements of the successive layers of air in such a wave may be represented by drawing a series of semicircles joining one another, dividing the semicircumferences into equal parts, and projecting them upon a straight line, as in Fig. 170. In this figure the movement of the wave is away from the sounding body, from the right toward the left, but the movement of the air is a slight to-and-fro motion: forward to produce a condensation, and backward to produce a rarefaction. A common method of representing a sound wave is given in the lower part of the figure, in which the parts of the curve above the straight line represent condensations, while those below

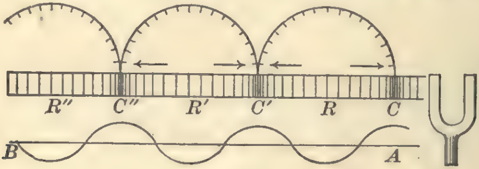


Fig. 170

the line represent rarefactions. The distance of any point of the curve from the straight line represents the extent of the rarefaction or condensation.

189. The Velocity of Sound in Gases. — The velocity of sound in air has been found directly by taking the interval between the time when the flash of a gun is seen, and the instant when the report is heard. The distance between the two stations, divided by the time in seconds, gives the velocity. The best results obtained by this method give the velocity of sound in air as 332.4 meters, or 1090.5 feet.

190. The Influence of Temperature. — If the above determination is made first in summer and then in winter, it is found that the velocity obtained in summer is greater than that obtained in winter. The velocities that have been given are for the temperature of freezing water, or 0° Centigrade. The velocity at any temperature may be found by substituting the reading of the Centigrade thermometer in the following formula:

$$v = 332.4\sqrt{1 + .003665\,t} \qquad (41)$$

EXAMPLE. — Find the velocity of sound when the thermometer reads 26° Centigrade.

$$v = 332.4\sqrt{1 + .003665 \times 26}$$
$$v = 332.4\sqrt{1.09529}$$
$$v = 332.4 \times 1.046$$
$$v = 347.69 \text{ meters.}$$

If the distance is required in feet it can be found by substituting 1090.5 for 332.4 in Formula 41. For approximate calculations the increase in velocity due to a rise in the temperature may be taken as 60 centimeters or 2 feet per degree Centigrade, and 33 centimeters or 1.1 feet per degree Fahrenheit.

If it is desired to find the velocity of sound in any gas other than air, it can be found approximately by dividing the velocity in air by the square root of the density of the gas. This gives

$$v = \frac{332.4}{\sqrt{d}}. \tag{42}$$

191. The Velocity of Sound in Liquids. — An expression for the velocity of sound in any medium is

$$v = \sqrt{\frac{e}{d}}. \tag{43}$$

This may be stated as follows: *The velocity of sound in any medium is directly proportional to the square root of the elasticity of the medium and inversely proportional to the square root of its density.* The comparative velocity of sound in air and in liquids will depend upon the relative values of e and d. The velocity of sound in water has been determined by striking a bell under water, and firing a quantity of powder at the same time. The sound of the bell was received by a specially formed hearing trumpet. The distance between the two stations, divided by the time between the flash and the hearing of the bell, gives the velocity. In an experiment on the lake of Geneva, with the boats about 8 miles apart, the velocity was found to be 4.3 times the velocity in air.

192. The Velocity of Sound in Solids. — The direct measurement of the velocity of sound in solids is made with considerable difficulty, since it is so great that the stations must be far apart. Measurements have been made, however, and the velocity in copper has been found to be about 11.1 times as great as in air, and in steel wire 15 times as great.

If the ear is placed close to a long wire, or to a rail of a railroad, a blow struck upon the wire or rail at a distance will give two reports, the first through the solid, and the second through the air.

193. The Reflection of Sound. — In Experiment 80 the wave sent along the spring is reflected from the fixed end. This reflection is that of a longitudinal vibration, and sound vibrations are reflected in a similar manner. The laws are the same as those for reflected motion. A good illustration of the effect of reflected sound is obtained by standing in an archway with the head, if possible, in the center of the arch. Then if a slight hissing sound is made, it will be reflected to the ear from all points of the arch and be very much increased in volume.

194. Echoes. — Whenever a sound is repeated by being reflected from any surface, it is heard as an *echo*. The distinctness of the echo depends upon how fully the sound is reflected, while the length of the sound it will repeat depends upon the distance of the reflecting surface. If it takes one second to pronounce a word, and if the speaker hears the echo as soon as the word is pronounced, his distance from the reflecting surface is about 166.2 m. (one half of 332.4 m.), since in that case the sound must go from the speaker to the reflecting surface and back in one second. If a single syllable is pronounced in one fifth of a second, the surface must be at least 33.24 m. away to produce a distinct echo.

195. Multiple Echoes. — When a sound is made between two parallel cliffs, the echo is repeated many times, and this forms a *multiple* echo. Two stones sharply struck together between two parallel buildings will produce a rattling sound like hail. If the character of the shore of a lake is known, a boat may be located at night by hallooing and listening for the direction of the echo.

PRACTICAL QUESTIONS AND PROBLEMS

1. When the wind blows over a field of grain a series of waves is set up. Describe the motion of the waves and of the heads of grain.

2. How do fishes hear?

3. Let $W =$ the wave length of a given sound, N the number of vibrations, and v the velocity. Write three equations, giving the value of each element in terms of the other two.

4. A flash of lightning is seen, and 6 sec. later the thunder is heard. How far away was the lightning, the temperature being 24° C.?

5. A certain island is $2\frac{1}{2}$ mi. from a quarry on the mainland. How long after a blast is fired will it be heard on the island, the temperature being 0° C.?

6. A cannon ball is fired against a target 2 mi. away, with an average velocity of 1200 ft. per second. Which reaches the target first, the ball or the sound of the firing? What is the interval between them when the temperature is 16° C.?

7. A gun is fired at A, 3216 ft. from B. How long a time afterward is the report heard at B, when the temperature is 21° C.? How long after this is the echo heard that comes from a cliff 2182 ft. from B, and 1496 ft. from A? Draw a figure showing the conditions.

8. Why can the noise of a coming train be heard by placing the ear upon the rail, before it can be heard through the air?

9. If 6 syllables can be pronounced in a second, how many can be heard in the echo from a wall 823 ft. distant, the temperature being 23° C.?

LABORATORY WORK

1. Modify Experiment 74 by using a Florence flask and fitting to it a rubber stopper with two holes. Push a brass rod tightly through one of these and fit a short glass rod to the other. Tie a small bell to the end of the brass rod, put it in the flask and ring the bell. Can you hear it ring? Next, put a little water in the flask and boil it. When the water is nearly all boiled away, remove the source of heat, put in the glass plug, and again ring the bell. Cool the flask by pouring cold water over the outside, and ring again. Explain the results.

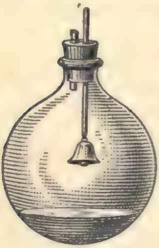


FIG. 171

2. Determine the velocity of sound in air directly by stationing one of a party at a measured distance

2000 ft. for example, from the rest. Let him fire a gun and let the rest take the time from the seeing of the smoke to the hearing of the report. The time can best be taken by making a pendulum with a bullet and a thread of such length that the pendulum will vibrate once every half second. Let one student put this in motion and count its vibrations aloud. The signal can then be given to fire, and the interval of time noted. Repeat a number of times at this distance, then increase the distance to 3000 ft. and repeat.

3. Determine the velocity of sound in the rails of a railroad track as follows: Station two students at a distance of 3000 ft. from the rest. Let one signal with a handkerchief the instant the other strikes the rail with a heavy hammer. Set in motion a pendulum like the one used in No. 2. Signal for the blow. Let one student say "go" when the blow strikes, and another with his ear to the rail say "go" when he hears the sound of the blow, while the rest note the number of vibrations of the pendulum. Repeat several times and compare the results with the time it takes the sound to pass over the same distance in the air. The pendulum in this experiment should be shorter than in No. 2. Estimation of parts of a vibration must be made in both.

4. Make a pendulum that will vibrate half seconds, and suspend it in front of a board in such a way that its vibrations shall be parallel to the board. Draw a heavy black line directly behind the vertical position of the pendulum. Fix the board and pendulum to a base so that it will stand steadily, as in Fig. 172. Take the apparatus to some place in front of a vertical wall, and, having adjusted the pendulum until it beats half seconds accurately, strike two blocks together just as the pendulum passes the vertical line. Listen for the echo and vary your position nearer to the wall or farther from it, until the echo reaches the ear at exactly the time that the pendulum recrosses the line. Measure your distance from the wall and determine the velocity of sound.

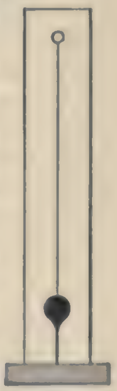


FIG. 172

II. INTERFERENCE, RESONANCE, AND MUSIC

196. Interference in Wave Motion. — EXPERIMENT 81. — Fasten the end of the spring coil used in Experiment 79 to a hook in a wall, and holding the other end in the hand, strike it a light vertical blow. A wave will be started that will run the length of the spring and be reflected from the other end to the hand. If a second blow is struck just as the reflected wave starts back, the direct and reflected waves meet and there will be some one part of the spring where the tendency of one wave to raise the spring will be exactly balanced by the tendency of the other wave to lower it.

This effect is called *interference.* Interference is a phenomenon attendant upon all wave motion, and arises from the fact that a medium that will transmit one wave motion will also transmit others at the same time. If the resultant of all the forces acting upon a particle at any time is reduced to zero, the result will be no motion, or interference.

EXPERIMENT 82. — Pour mercury into a flat dish of considerable area. Drop a bicycle ball into it at different places and observe the points of interference between the direct and reflected sets of waves.

197. Interference of Sound. — Interference being characteristic of wave motion, we may expect to find it one of the phenomena of sound.

EXPERIMENT 83. — Set a tuning fork in motion and hold it in a vertical position in front of the ear. Holding it between the thumb and finger, rotate it; the sound, instead of being uniformly loud, will be made up of pulsations, the sound very nearly dying out and then becoming full and strong again. Why?

EXPERIMENT 84. — Sound a tuning fork, — preferably one with a sounding box, as in Fig. 173, — and move it rapidly toward, and then away from, a smooth wall. Observe the interference that takes place. Can you find more than one place where the sound interferes?

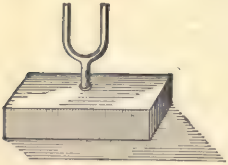


FIG. 173

198. Resonance. — When two forces act in the same direction upon a vibrating particle, they increase the amplitude of the vibrations, and the resultant amplitude is the sum of the two. As an example, suppose two sets of water waves are running over the surface of a lake; if one wave lifts a particle of water three feet and another raises it two feet at the same time, the resulting wave at that point will be five feet high. Such an effect in sound waves gives rise to a reënforcement of the sound, called *resonance.*

EXPERIMENT 85. — Fill a tall glass jar nearly full of water, and get a piece of large glass tubing about a foot long, or the chimney of a student lamp. Hold a sounding tuning fork over the upper end of the tube, and push the lower end into the water as shown in Fig. 174, until the air in the tube responds to the tone of the fork and strengthens it.

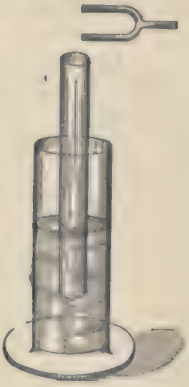


FIG. 174

This result is *resonance*, and the tube is a *resonator.*

199. Principle of the Resonator. — In order that the sound of the fork may be strengthened by the resonator it is necessary that the condensation started by the prong *A* in its downward vibration (Fig. 175) shall go to the bottom of the tube *B* and be reflected to *A* in time to join the condensation produced by *A* in its upward vibration. If, however, the distance *AB* is such that the reflected condensation meets a rarefaction, interference will result and the sound of the fork will be weakened.

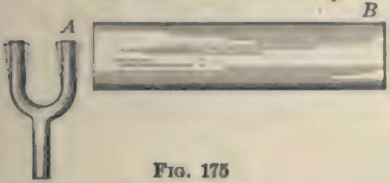


FIG. 175

200. Relation of Velocity, Number of Vibrations, and Wave Length. — When a body is sounding continuously, the air between it and a person who hears it is filled with an uninterrupted series of waves. The number of these waves that strike the ear will depend upon the rate of vibration of the sounding body, and the velocity of sound in the air will be the product of the wave length by the number of vibrations per second. For example, if the wave length is 4 feet and the vibrating body sends out 280 waves per second, then the front of the first wave will be 1120 feet away from the sounding body when the 280th vibration is finished. Hence we may write

$$v = NL. \tag{44}$$

201. Measurement of the Velocity of Sound by a Resonance Tube. — It is quite possible to measure the velocity of sound in air by comparing the length of the air column in the resonating tube with the number of vibrations per second. A convenient form of tube and support for this measurement is shown in Fig. 176. The tube *A* is 11 mm. in internal diameter; at its lower end it is drawn out and connected by a flexible rubber tube to a similar glass tube fastened to the wooden arm *B*. This arm is movable,

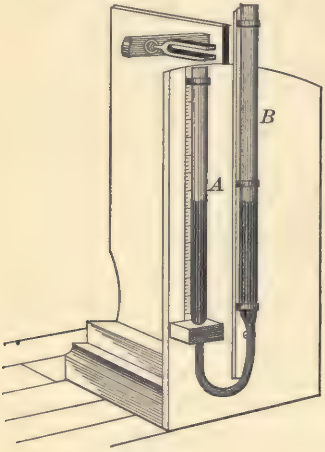


FIG. 176

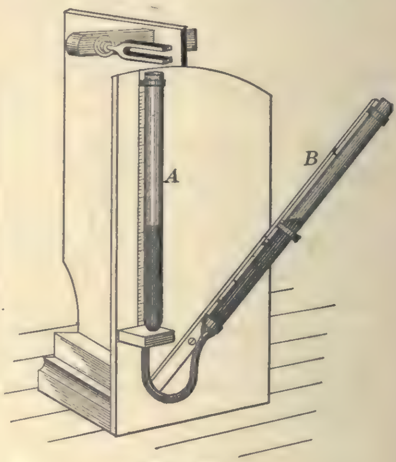


FIG. 177

as is shown in Fig. 177, moving with so much friction that it will stay in any position. Back of the tube A is a scale graduated in millimeters, the zero being the position of the fork. At a right angle to the main vertical support is another which is so arranged that forks of various lengths may be held in position. By pouring water into the tube and moving *B* from the vertical position, the length of the air column in A can be so fixed that it will resound to the fork. When this is carefully determined, its length can be read on the millimeter scale. To find the velocity of sound from this measurement it must be remembered that since the pulse of air first given out by the fork must go to the bottom of the tube and back, that is, twice the length of the tube, while the fork is making half its vibration, it will go four times that length while the fork is making a complete vibration. This means that *the wave length of the fork is 4 times the length of the air column.* Calling the measured length in mm. l, we may write $L=4l$. Substituting this in Formula 44, we have $v=4\,lN$. Experiments with tubes of different diameters show that a correction must be made for the diameter; that is, in order to get correct results a certain fractional part of the diameter must be added to the length to get one quarter the wave length. Lord Rayleigh gives this fraction as one half. Including this correction in the formula it will stand

$$v=4\,N(l+r). \qquad (45)$$

202. Practical Effects of Resonance. — The effects of resonance are very marked in musical instruments. A tone produced by a vibration in which only a small quantity of air is put in motion is thin. Fullness of tone can be secured only by putting a large mass of air in motion. For this reason stringed instruments have for the body of the instrument a wooden resonator box, as in the violin and the guitar.

Experiment 86. — Hold a toy music box in the hand and play it. Place it upon a table and play it. Hold it against the glass door of a bookcase and play it. Explain the results.

203. Sympathetic Vibrations. — Experiment 87. — Stretch a strong cord, AB (Fig. 178), between two supports, and from two points C and D suspend two pendulums of exactly the same length. Put E in motion and it will be found that as it loses motion F takes it up, and when E is at rest, F will be vibrating with nearly the same amplitude that E had at first.

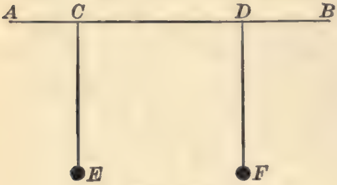


Fig. 178

Whenever a sounding body is near another that has the same time of vibration, it is found that the pulses of air sent out by the first will put the second in motion.

Experiment 88. — Select two tuning forks that are mounted upon resonance boxes, and that give the same number of vibrations per second. Place them parallel to each other at opposite ends of a table, and put one of them in vibration with a heavy bow. Stop its vibrations with the fingers, after a few seconds, and the second fork will be heard. Its vibrations may also be shown by suspending a light ball by a silk thread so that it will just touch one side of the fork.

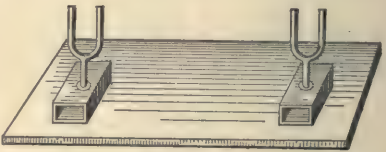


Fig. 179

Experiment 89. — Press down on the pedal of a piano so as to remove the dampers from the strings, and then sing in a clear voice in front of it some note for two or three seconds. This will set in vibration both the string which vibrates in the same time as the note, and all those strings whose vibrations are multiples of the number given by the note.

EXPERIMENT 90. — Suspend from a hook in the ceiling a 20-pound weight, and find the time in which it will vibrate as a pendulum. Strike the weight light blows with a cork hammer, when it is at rest, timing the blows to the same time in which it vibrated. If the blows are given at the right times the result will be to set the pendulum swinging.

204. Beats. — When two sounding bodies that do not vibrate in the same time are vibrating near each other, the effects produced by the alternate interference and coincidence of the two waves are called *beats*. These beats can be readily detected by the ear. If the waves sent out by the two sources are represented by the lighter curves in Fig. 180, we can see that one body must vibrate three times while the other vibrates four. This means that at every fourth wave of one, and every third wave of the other, the waves will interfere, while at times midway between the waves will assist each other. The curve resulting from these two sets of waves is shown in the heavy line. This would be heard by the ear as a beat at that part of the curve which is at the greatest distance from the straight line AB, while midway between the beats, where the interference is nearly complete, there would be very little sound. To construct the resulting heavy line we proceed as follows: Draw a set of vertical lines across AB; then will any point on the curve be found by making ad equal to the sum or difference of ab and ac, depending upon whether they are upon the same or opposite sides of AB.

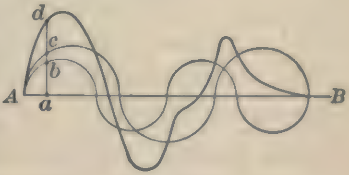


FIG. 180

EXPERIMENT 91. — Arrange two tuning forks as in Experiment 88, and load one prong of one of them by pressing a piece of beeswax upon it, near the end. It may be necessary to press one or two large shot into the wax. Set the fork in vibration with the bow and count the number of beats per second.

205. Properties of Musical Tones. — In order that a vibrating body may produce a musical tone its vibrations must be rapid, continuous, and isochronous. A musical tone may be a *simple tone*, in which the vibrations are all alike, or it may be a *compound tone* formed of a combination of two or more vibrations. A *noise* differs from a musical tone in being formed by a mixture of a great variety of vibrations that cannot be resolved into simple ones. A tuning fork gives a simple tone, a piano string a compound tone, while the fall of a pile of lumber makes a noise.

The principal characteristics of musical tones are *pitch*, *intensity*, and *quality*.

206. Pitch. — The pitch of a tone depends upon the number of vibrations made per second by the vibrating body that produces it, the pitch being relatively high when the vibrations are rapid, and low when they are slow.

EXPERIMENT 92. — Draw the corner of a stiff card several times across the cover of a book. Move it slowly at first and then more and more rapidly. What effect does the velocity have upon the pitch?

207. Savart's Wheel. — The first instrument used to show the relation of pitch to number of vibrations was what is called *Savart's wheel.* This consists of a toothed wheel so mounted on an axle that it can be put in rapid rotation. When a stiff card is held against the teeth any change of speed is accompanied by its corresponding change of pitch. A clock wheel can be used for the same purpose.

The speed at which a circular or "buzz" saw is running can be judged by the pitch of the note which it gives when sawing a log. A knot in the log lessens the speed and lowers the pitch of the note.

208. The Siren. — The name *siren* is given to an instrument used to determine the number of vibrations required to produce tones of different pitch, as well as to show the relation between them. A simple form and the method of using it is described in the following experiment.

EXPERIMENT 93. — Cut out a disk of bristol board, or, better, of some thin metal, 30 cm. in diameter. From the center *C*, describe 4 concentric circles, with diameters of 28, 24, 20, and 16 cm. respectively. Divide these circles into 32, 24, 20, and 16 parts respectively, and drill holes 6 mm. in diameter through the disk at these points; the inmost of these four circles of holes being shown in Fig. 181.

Drill a hole at *C* and fit the disk to a rotating machine. Into each end of a rubber tube fit a glass tube; and holding one end directly opposite to one row of holes, put the disk in rotation and blow through the tube. If the rotation is begun very slowly, the separate puffs of air as they go through the holes in the disk and are then cut off, will be heard, but if the speed is increased, the puffs will link themselves into a musical tone and the pitch will continue to rise as long as the speed is increased.

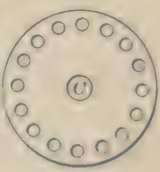


FIG. 181

Rotate the wheel with uniform velocity and blow through the holes in the different circles, beginning with the smallest and going to the largest. Is the result pleasing? Describe it.

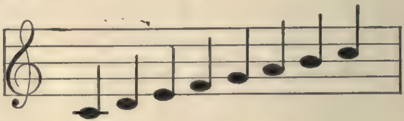
209. Doppler's Principle. — When both the sounding body and the ear that hears it are stationary, the number of waves that strike the ear is the same as that sent out by the vibrating body; but if either moves from a position of rest, either toward or away from the other, the number of vibrations that reach the ear, and consequently the pitch of the note heard, is changed.

If n represents the number of vibrations of the sounding body, l the wave length, and d the distance over which the ear moves toward it in one second, then the number of vibrations heard by the ear will be $n + \frac{d}{l}$, and the pitch will be raised. The sounding body may itself be moving, or both it and the ear may be moving. If the distance between the bodies is increasing, the number of vibrations received will be $n - \frac{d}{l}$, and the pitch will be lowered. A good example of this effect is noticed when one train meets another while the bell of the engine on the second train is ringing.

210. Musical Intervals. — The change of pitch that takes place when the velocity of the siren is slowly increased is a gradual one, but between any two notes used in music there is a definite difference in pitch. This is expressed by the ratio of the vibration-numbers of the notes. If one fork vibrates three times while another is vibrating twice, the interval is 3 : 2.

211. The Musical Scale. — When the interval between two notes is 2 : 1, the notes resemble each other so closely that they are practically the same note. The one with double the number of vibrations is called the *octave* of the other, since it is the eighth note in what is called the *scale*. The notes in the scale have received various names and are represented by their positions with respect to a series of five parallel lines called a staff. These names and positions are shown as follows :

Staff and position . . . .



Number in scale	1	2	3	4	5	6	7	8
Letter names	*c'*	*d'*	*e'*	*f'*	*g'*	*a'*	*b'*	*c''*
Syllable names	*do*	*re*	*mi*	*fa*	*sol*	*la*	*si*	*do*
Relative number of vibrations . .	256	288	320	$341.\dot{3}$	384	$426.\dot{6}$	480	512
Ratio of vibrations	1	$\frac{9}{8}$	$\frac{5}{4}$	$\frac{4}{3}$	$\frac{3}{2}$	$\frac{5}{3}$	$\frac{15}{8}$	2
Intervals		$\frac{9}{8}$	$\frac{10}{9}$	$\frac{16}{15}$	$\frac{9}{8}$	$\frac{10}{9}$	$\frac{9}{8}$	$\frac{16}{15}$

212. The Diatonic Scale. — The series of eight tones, through which we pass from *c* to its octave, constitutes the *diatonic scale*. The musical and physical methods of representing this scale are shown in § 211. The scale is extended into the higher pitches by taking the *do* of 512 vibrations as unity, and multiplying this number by the ratio of vibrations. The letter names would be c'', d'', etc. The next octave below is found by taking the *do* of 256 vibrations as 2. Then the *do* an octave below will have 128 vibrations, and with this as unity the vibrations can be determined for any note. These notes are called *c*, *d*, etc.

213. The Major Chord. — The scale given in § 211 is the *major scale* formed upon the *major triad* or *chord*. This chord consists of any three notes, the numbers of whose vibrations are in the proportion of 4, 5, and 6. There are three major chords, as follows:

$$\text{Tonic} = c' : e' : g' = 4 : 5 : 6$$

$$\text{Dominant} = g' : b' : d'' = 4 : 5 : 6$$

$$\text{Sub-dominant} = f' : a' : c'' = 4 : 5 : 6.$$

A comparison of the first notes of these chords will suggest the origin of the name of the *Tonic sol-fa* system of musical notation.

214. Intervals in the Scale. — The series of ratios 1, $\frac{9}{8}$, $\frac{5}{4}$, $\frac{4}{3}$, etc., that express the relative number of vibrations, also express the intervals between the *do* and other notes of the scale. The most important of these intervals are the *major third*, 5 : 4; the *fifth*, 3 : 2; the *major sixth*, 5 : 3; and the *octave*, 2 : 1.

215. The Keynote. — The note which is taken as the *do* or 1 of any scale is its *keynote*. The scale already considered has c' for its keynote and is in the key of *C*.

Suppose we form a scale with g' for its keynote and compare the number of vibrations in its various notes with those in the key of *C*.

	g'	a'	b'	c''	d''	e''	f''	g''
Key of *C*	384	$426.\dot{6}$	480	512	576	640	$682.\dot{6}$	768
Key of *G*	384	432	480	512	576	640	720	768

We see by this comparison that there are two notes each represented by a' and by f'', which differ in the number of their vibrations. The interval for the two a''s is $432 : 426.\dot{6}$ or $81 : 80$. This is called a *comma*. The f'''s differ more widely, their interval being $135 : 128$. This is sometimes called a *semitone*. In order to play music accurately in the key of *G*, two tones that are not found in the key of *C* would be required. One of these, the f'' of the key of *G*, is introduced approximately by increasing the vibrations of f'' in the key of *C* by multiplying the number by $\frac{25}{24}$; this new note is called f'' *sharp* or $f''\sharp$. The number of vibrations for a' in the key of *G* differs so little from that for the same note in the key of *C*, that in most instruments the one tone serves for both.

Inasmuch as any note in the scale may be taken for the keynote, it is evident that to introduce two new notes for every new scale on such an instrument as the piano would make the keyboard so large that it could not be used at all. Other complications come in also when what are known as the *flat keys* are used. In these the new tone required by the ratio of vibrations is secured by lowering the number of vibrations of the corresponding note by multiplying it by $\frac{24}{25}$. The resulting note is called the flat of the first, as *b flat* or $b\flat$. It is evident that between c' and d' there would be two notes, as follows: c', $c'\sharp$, $d'\flat$, d', having for their respective vibrations, 256, $266.\dot{6}$, 276.48, 288.

In practice there is but one key on the piano between *C* and *D*, and this is called either *C*♯ or *D*♭. The system adopted to fix the number of vibrations for each of the thirteen notes of each octave on the piano is called the system of equal temperament. The twelve intervals (semitones) in the scale are made equal, and this interval is $\sqrt[12]{2}$ or 1.0594. The scale of thirteen notes is called the *chromatic scale.*

216. Transposition. — It will be seen by reference to the keyboard of a piano that in the scale of *C* there is a semitone between the 3d and 4th and between the 7th and 8th of the scale, while the rest are all whole tones. This is true of any major scale, and music written in one key may be *transposed* into another by introducing the proper sharps or flats to bring these semitones in their proper places. This is illustrated in Fig. 183. By reference to this figure, it will be seen that the scale for the key of *G* is formed from the scale for the key of *C* by taking the 5th of the key of *C* — *sol* — for the first of the new scale and raising the 7th of the new scale a semitone. This introduces only one sharp — *F*♯ — as all the other notes correspond with those in the scale of *C*. The scale for the key of *D*, two sharps, is formed from the key of *G* in the same way. The scale for any key in which the number of sharps is increased by one, may be made from the scale before it by taking the 5th of that scale for its 1st note and sharping the 7th. One may find any note in any key, having only a *C* tuning fork to start with. For instance, to find *mi* in the key of *G*, sing the scale of *C* from *do* to

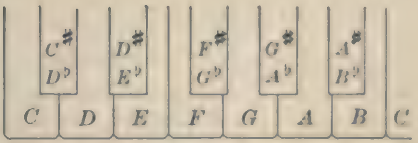


Fig. 182

sol, then call this same tone *do*, and on singing *re* and *mi* the note is found in the required scale.

Flat Keys		C	Sharp Keys	
B^b	F		G	D
3 — D'	6 — D'	2 — D'	5 — D'	8 — D'
				7 — $C'^\#$
2 — C'	5 — C'	8 — C'	4 — C'	
		7 — B	3 — B	6 — B
8 — B^b	4 — B^b			
7 — A	3 — A	6 — A	2 — A	5 — A
6 — G	2 — G	5 — G	8 — G	4 — G
			7 — $F^\#$	3 — $F^\#$
5 — F	8 — F	4 — F		
	7 — E	3 — E	6 — E	2 — E
4 — E^b				
3 — D	6 — D	2 — D	5 — D	1 — D
				7 — $C^\#$
2 — C	5 — C	1 — C	4 — C	
		7 — b	3 — b	6 — b
1 — b^b	4 — b^b			
7 — a	3 — a	6 — a	2 — a	5 — a
6 — g	2 — g	5 — g	1 — g	4 — g
			7 — $f^\#$	3 — $f^\#$
5 — f	1 — f	4 — f		

FIG. 183

Fig. 183 also shows that the flat keys are formed by taking the 4th note of the old scale for the 1st of the new, and flatting the 4th of the new scale.

217. Intensity. — The intensity of a sound depends upon three things: the amplitude of the vibration producing it, the distance at which it is heard, and the area of the sounding body.

(*a*) *Amplitude.* — If a tuning fork is struck, the energy which it can impart to the air will depend upon the extent of its vibrations. If these are slight, the energy imparted to the air will soon die out. Strike a harder blow, and the amplitude increases, the energy the fork can give to the air is greater, and the sound is louder. The relation between amplitude and intensity may be readily shown by substituting a tuning fork for the whalebone in Experiment 78. Make a number of traces on the smoked glass when the fork is sounding at different intensities, and compare them.

(*b*) *Distance.* — Since the sounding body is sending out waves in every direction, the sound wave is the outside of a spherical shell of which the body is the center. As the surfaces of spheres are proportional to the squares of their radii, we can say that intensity of sound varies inversely as the square of the distance from the sounding body. If the waves of sound can be kept in one direction, as by being reflected from the inner surface of a tube, they will go much farther. On this principle speaking tubes are made.

(*c*) *Area.* — A small tuning fork, on being put into vibration, sets only a small quantity of air in motion and gives a sound having but little intensity, but if the prongs are broad the amount of air put in motion is greater and the sound is much louder. If a tuning fork is struck and held in the hand, its tone will be light and thin, but if the handle is held against the glass door of a bookcase, the sound will be louder, but will not last so long. Why?

218. Quality or Timbre. — Whenever we hear a musical sound we have no difficulty in recognizing the kind of instrument that produces it. The violin, the piano, the cornet, has each its own peculiarity. One voice is full and rich, another is thin, and another is monotonous. The characteristics which enable us to assign a sound to its source are called the *quality* of the tone. The physical explanation of quality is that most sounding bodies vibrate not only as a whole, but in various parts, as does the string of a piano, and that a sound is rich in quality when it contains the 1st, 2d, 3d, etc., overtones (p. 193), as well as the fundamental note of the vibrating body.

219. Harmony and Discord. — Two musical sounds are said to produce harmony when, on being sounded together, they produce a result pleasing to the ear. If the result is unpleasing, they are said to produce discord. One cause of discord is the presence of beats between the two notes, and the greatest discord results when the beats are about 32 per second. If the number of beats is fewer than 10 per second, they are not agreeable, but do not produce discord. Discord is caused by sounding together notes that give more than 10 and less than 70 beats per second.

PRACTICAL QUESTIONS AND PROBLEMS

1. Under what conditions will two wave motions completely neutralize each other?

2. How long must a tube be to act as a resonator for a tuning fork that vibrates 440 times per second, when the temperature is 18° C.?

3. What is the velocity of sound when the length of the resonator column in Fig. 177 is 324 mm., the diameter of the tube is 12 mm., and the tuning fork makes 256 vibrations per second?

4. Why do soldiers break ranks in crossing a bridge?

5. How many beats per second will be made by two tuning forks, sounding together, when one makes 264 vibrations per second, and the other 260?

6. Construct a curve to show the beat that would result from sounding a note and its seventh, *C* and *B*. Strike these notes on the piano and listen for the beat. Is it distinctly audible or does it produce discord?

7. Suppose the outer row of holes in the siren of Experiment 93 gives the note $c' = 256$ vibrations. How many times does the disk rotate per second? What notes will the other rows give?

8. Suppose an engine passes you at the rate of 30 miles per hour; what change of pitch will take place in the whistle when it passes you, if it vibrates 128 times per second? What number of vibrations will strike the ear before and after it passes?

9. Write the numbers of vibrations that will give the major scale in the key of *A*; in the key of *B*♭.

10. How many vibrations will give f'♯ and g'♭?

11. Show how you would transpose from the key of *C* to the key of *A*♭.

12. A katydid in a tree 40 ft. above the ground is heard at its foot. What is the weight of the air put in motion by its note?

13. In the time of Handel (about 1750) the standard fork gave 424 vibrations for *a′*. Modern instrument makers, however, kept raising the pitch of their instruments to secure brilliancy of tone, until the *a′* fork made 460 vibrations per second, about 1½ semitones above Handel's *a′*. What effect would this have upon the difficulty of singing the high notes of a song written in Handel's time? The present standard pitch is the International, in which the *a′* fork makes 435 vibrations at 15° C.

LABORATORY WORK

1. Set a pail or pan of water on the frame of some rapidly moving piece of machinery, as a buzz saw. Make a drawing of the form of wave motion set up. Explain.

2. Measure the velocity of sound by the apparatus shown in Fig. 177, using a fork with a known number of vibrations.

3. Find the number of vibrations of a second fork by using the same apparatus and substituting, in Formula 45, the velocity found in No. 2.

4. Repeat Experiment 88 after loading the second fork until there are about six beats per second.

5. With the siren used in Experiment 93, find the pitch of sound produced by blowing across the mouth of a bottle. Four students will be needed. Let one blow across the bottle, another turn the wheel, the third blow through the holes with the rubber tube, and the fourth count the number of rotations made by the wheel per minute. A little practice will enable one to turn the disk uniformly, so as to keep the siren at the same pitch for half a minute.

6. Connect two T-tubes by two rubber tubes as shown in Fig. 184. Sound a tuning fork before the funnel at *A* and the sound will divide at *B*, part of it going through the upper branch *C*, and part through the lower branch *D*. The two waves will unite again at *E*, and if the ear is placed at the end of a rubber tube leading from *E*, it will be found that when the distance *BDE* is greater than *BCE* by half the wave length of

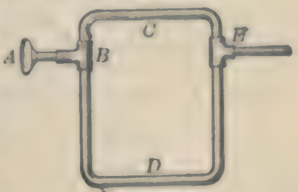


FIG. 184

the fork, the waves will interfere and produce silence. When the tubes are of the proper length to produce this result, pinch the tube together at *C* or *D* and observe the result. Find the length of tube for two or more forks.

III. Vibration of Strings, Plates, and Rods

220. The Vibration of Strings. — A number of important musical instruments are stringed instruments, and depend for their sound upon the transverse vibration of catgut or metal strings stretched between posts. The sound made by the strings is strengthened by the vibration of the sounding body of the instrument.

221. The Sonometer. — To investigate the laws of the vibration of strings an instrument called the *sonometer* is used. This is also called a *monochord*, since a single string is frequently used. The essential parts are a base with a bridge at each end, a pin to which to fasten one end of the string, and some method of stretching the string by attaching a spring balance or weights at the other end. A common form, with two strings, is shown in Fig. 185. A movable bridge at *E* is used to change the length of the vibrating string, and a scale is laid off on the base.

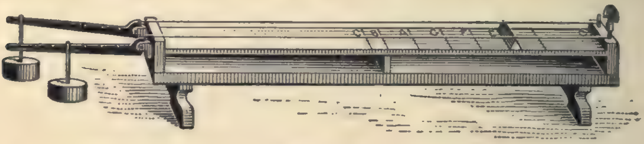


Fig. 185

222. Laws of the Vibration of Strings.

I. *The tension, diameter, and density being the same, the number of vibrations per second varies inversely as the length of the string.*

II. *The length, tension, and density being the same, the number of vibrations per second varies inversely as the diameter of the string.*

III. *The length, diameter, and density being the same, the number of vibrations per second varies directly as the square root of the tension.*

IV. *The length, tension, and diameter being the same, the number of vibrations per second varies inversely as the square root of the density of the string.*

The above laws can be expressed by the proportion

$$N : N' = \frac{\sqrt{T}}{dl\sqrt{D}} : \frac{\sqrt{T'}}{d'l'\sqrt{D'}}$$

For the first law, under the conditions given, the proportion becomes

$$N : N' = \frac{1}{l} : \frac{1}{l'}, \text{ or, } N : N' = l' : l.$$

For the second law it is

$$N : N' = \frac{1}{d} : \frac{1}{d'}, \text{ or, } N : N' = d' : d,$$

for the third law, $N : N' = \sqrt{T} : \sqrt{T'}$,

and for the fourth law,

$$N : N' = \frac{1}{\sqrt{D}} : \frac{1}{\sqrt{D'}}, \text{ or, } N : N' = \sqrt{D'} : \sqrt{D}.$$

These laws can be verified on the *sonometer* as in the following experiments:

EXPERIMENT 94. — Stretch the wire of the sonometer by a weight until a suitable note is produced on setting it in vibration with a bow. Find the exact middle of the string. Place the movable bridge at that point and observe that either half of the wire will give the octave of the whole.

EXPERIMENT 95. — Place on the sonometer two brass wires, one having a diameter twice that of the other, and stretch them with equal weights. (Wires Nos. 16 and 22 fulfill the requirements.) Draw the bow across the larger wire and rotate the disk siren until the same tone is obtained by blowing in the outer row of holes. Keep the siren rotating at the same speed, and it will be found, on blowing through the inner row of holes, that the same tone is obtained as on drawing the bow across the smaller wire.

Experiment 96. — Put on the sonometer two wires of the same material and diameter. Stretch one with a weight of 4 lb. and the other with a weight of 16 lb., and they will be found to give tones an octave apart.

Experiment 97. — Cut two strings of equal length and diameter, one of brass and the other of catgut. Weigh them separately and compute the weight of each between the bridges. Stretch them on the sonometer with equal weights, and sound them. Compare the tones given with those given by a piano or violin. Call the number of vibrations of the note corresponding to the lower tone given by the sonometer, N, and the number given by the other string, N'. Find whether the proportion $N : N' = \sqrt{D'} : \sqrt{D}$, is true or not.

Experiment 98. — Calling the distance between the bridges on the sonometer *one*, stick a narrow strip of gummed paper at distances of $\frac{8}{9}$, $\frac{4}{5}$, $\frac{3}{4}$, $\frac{2}{3}$, $\frac{3}{5}$, $\frac{8}{15}$, $\frac{1}{2}$, from one end. Sound the whole string first, then slide the movable bridge along, and, stopping at each mark, sound the remaining string. Do the notes give the major scale? Why?

The strings of the piano illustrate the above laws. The lowest notes are made by long, heavy strings without great tension, while the highest notes are made by short, light strings stretched to a high tension.

223. Nodes and Loops in Strings. — When a stretched string is put into vibration, it vibrates not only as a whole, giving its fundamental note, but also in halves, thirds, fourths, etc., each one of which gives its own tone. These different tones, with the fundamental, constitute the quality of the tone. The existence of nodes and loops in a string can be shown as follows: —

Experiment 99. — Cut from stiff writing paper a dozen paper rings about a half inch in diameter and slip them over a sonometer wire. Put a small weight upon the wire and with the bow put the wire in vibration. The wire will sound its fundamental note, and the rings

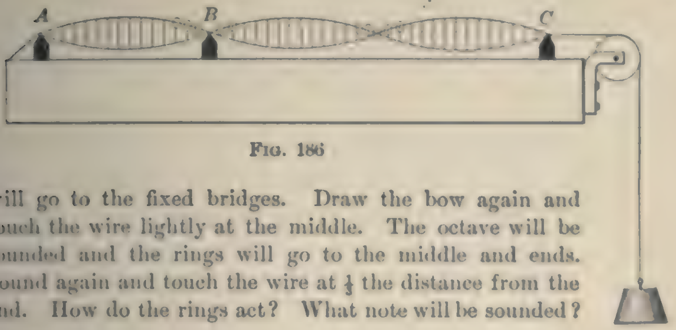


FIG. 186

will go to the fixed bridges. Draw the bow again and touch the wire lightly at the middle. The octave will be sounded and the rings will go to the middle and ends. Sound again and touch the wire at ⅓ the distance from the end. How do the rings act? What note will be sounded?

224. Overtones and Harmonics. — It is not necessary to touch the string in order to make it vibrate in parts besides vibrating as a whole. The tones caused by the vibrations in parts can be heard by listening carefully when the string is plucked. These tones are called *overtones*, and if the numbers of vibrations which produce them are 2, 3, 4, etc., times the number of vibrations of the fundamental they are called *harmonics*. Overtones can be very readily produced on a guitar and form the most accurate method of tuning it.

225. Vibration of Air Columns. — In the musical instruments called wind instruments, the notes are produced by the vibrations of columns of air, of different lengths. There are two methods by which the column of air is put into vibration; hence the classification into *mouth* and *reed* instruments. The organ pipe is a good example of the former, in which all parts of the mouthpiece are fixed, and the air column is put into vibration by blowing across a narrow opening at one end of the pipe. In the reed instrument the air column is thrown into vibration by a thin piece of wood or metal which is itself thrown into rapid vibration by a current of air. The clarinet and reed organ are examples of reed instruments.

226. Nodes and Loops in an Organ Pipe. — The vibration of air in a tube is in the direction of its length, but it can give rise to nodes and loops as well as a vibrating cord. In this case, however, the node must be understood to mean a point where the particles of the air remain at rest, but where there are rapid changes from condensation to rarefaction and *vice versa*. A loop means a point where there is the greatest motion, but no change of density. From this it will be seen that the closed end of a pipe must form a node, and the open end a loop. In *A* (Fig. 187), a node would be at the upper end and a loop at the mouth; consequently the length of a closed pipe is one fourth the wave length of its fundamental note. If the pipe is blown strongly, it will give out a note higher in pitch, but a node will still be at the closed end and a loop at the mouth. In this case (*B*) there will be an intermediate node and loop at N' and L', and the length of the tube will be three fourths the wave length of the note produced.

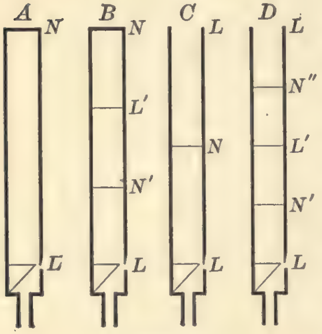


FIG. 187

In the open pipe, *C* (Fig. 187), there will be a loop at each end, and a node in the middle, and the length of the pipe will be half the wave length of the fundamental note. If the next higher note is produced there will be two nodes, N' and N'', and an additional loop L'. Comparing *A* and *C* (Fig. 187), it will be seen that the fundamental note given out by an open pipe of a certain length is the octave of the note produced by a closed pipe of the same length.

EXPERIMENT 100.—Procure an organ pipe, one side of which is glass, and lower into it, by a thread, a light ring over which is stretched a membrane with fine sand sprinkled over it, as shown in Fig. 188. When the fundamental note is sounded and the ring is lowered, the sand will show by its movements that the amount of the vibration is decreasing until the middle of the tube is reached, where it will come to rest. Increase the force of the bellows that blow the pipe, so as to produce the higher note; the middle point becomes a loop, as is shown by the dancing of the sand.

If an opening is made in the side of a pipe, this becomes a loop and changes the pitch of the note played. In this way the different notes of a flute are made by the fingers of the player stopping and unstopping the holes along its side.

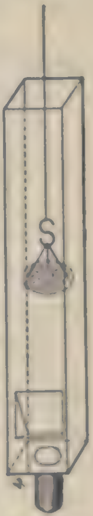


FIG. 188

227. The Vibration of Rods. — EXPERIMENT 101. —Hold a glass rod, a meter long or more, by the middle with one hand, while with the other you draw a moist cloth lightly from the middle to the end. The rod will be thrown into longitudinal vibrations, and the fundamental note will be produced. Make the same experiment with a wooden rod, a brass rod, and a brass tube of the same length, using a rosined cloth for a rubber. Does the pitch of the note depend upon the material of the rod?

EXPERIMENT 102.—Repeat experiment 101 with two glass tubes of different diameters, but of the same length. Does the pitch of the note depend upon the diameter of the tube? Compare the notes given by one of these tubes and another of the same diameter but only half as long. Does the pitch of the note depend upon the length? How do the two notes compare?

That the sound given out by the tubes and rods in the above experiments is due to longitudinal vibration may be shown by the following experiments:

Experiment 103. — Scatter some lycopodium powder or cork filings along the inside of one of the tubes used in Experiment 102. Hold the tube by the middle and draw a moist cloth from the middle to one end. The tube will give a high note, and the powder will be thrown into ridges lying across the tube at regular intervals. These ridges locate the nodes, as shown in Fig. 189.

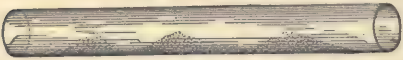


Fig. 189

Experiment 104. — Clamp a brass rod firmly to a block upon a table as shown in Fig. 190. Suspend an elastic ball so that it will rest against one end of the rod, and then draw a cloth covered with rosin from the middle to the other end. The longitudinal vibrations will cause the rod to give out a high note, and will repel the ball from the end of the rod.

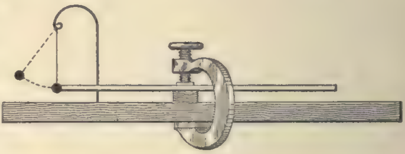


Fig. 190

The mechanical effect of vibrations in tubes is sometimes very great. It is not uncommon for a test tube to be cracked into a spiral ribbon running from end to end, on being wiped with a damp towel. If a glass bell jar is bowed vigorously a few times with a violin bow, it may be shattered even if the walls are a quarter of an inch thick.

228. The Vibration of Plates. — If a thin plate of metal or glass is clamped to a support at the middle, and a bow is drawn across its edge, it will be thrown into vibration and will produce sound. The positions of the nodal lines of the plate can be shown very readily as follows:

Experiment 105. — Sift sand evenly over the surface of a brass plate fastened by the middle as the first one in Fig. 191. Place a finger at one corner and draw a bow across the middle of either side. The sand will be thrown violently about, and will finally come to rest on those parts of the plate that do not vibrate, so that the lines of sand indicate the nodal lines. Fig. 191 shows a number of plates of various forms, sizes, and thicknesses, and a few of the many interesting figures that can be produced by them. If the plates are clamped by the corner or at one side a new set of figures will be obtained.

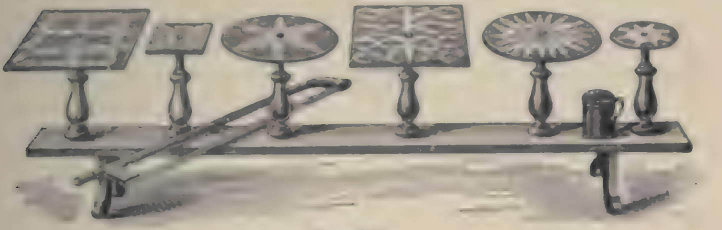


FIG. 191

EXPERIMENT 106. — Scatter a little lycopodium powder on the plate with the sand, and it will be found, on vibrating the plate, that the powder will collect over the places of greatest vibration instead of at the nodal lines as the sand does. Examine carefully and explain why this happens.

229. Graphical Method of Combining Vibrations. — It is frequently desirable to represent in a graphical way the relation that exists between the vibrations of notes of different pitches. The method usually adopted is to consider the vibrations of the two bodies to be made at right angles with each other, and to construct a curve that will be the result of the two vibrations combined. If a ball A (Fig. 192) is moving around a circular path with uniform motion, then, to an eye placed a considerable distance* away in the plane of its motion, it will seem to move back and forth over the diameter AC, with a *simple harmonic motion* like that of a pendulum. The distance it has gone toward C at any time may be found by projecting its

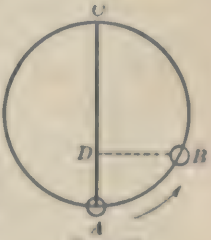


FIG. 192

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* Strictly, the distance should be infinite.

position upon the diameter *AC* as at *D*. If the vibrations producing the notes *c* and *f* are to be combined, the curve can be made graphically as follows:

Suppose a point moving uniformly around the circle at *H* to represent the vibrations that produce *c*, and one at *D*, those that produce *f* (Fig. 193). Since the ratio of the numbers of vibrations in these two notes is $1:\frac{4}{3}$, the body sounding the note *f* vibrates eight times while the body sounding *c* vibrates six times. Lay off the circumference *DEF* into six equal parts and the other circumference into eight. From the points of division draw lines perpendicular, respectively, to *AB* and *AC*, and prolong them; then will their intersections give the points for the required curve. In order that the curve connecting the points shall be smooth, intermediate points must be determined.

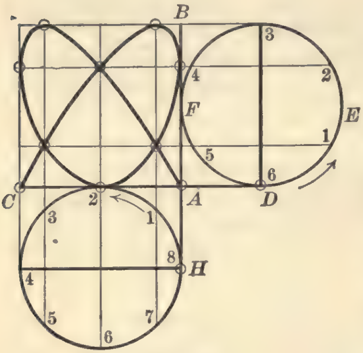


Fig. 193

The curve representing the combination of any other two notes can be constructed in the same way.

230. The Optical Method. — An optical method is one in which the curve is formed by the vibrating bodies in such a way that it can be seen and studied by the eye.

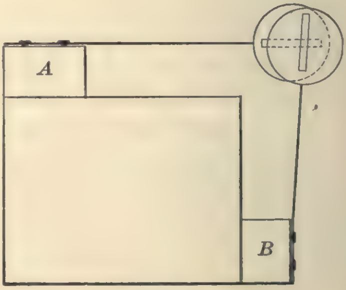


Fig 194

Experiment 107. — Nail two blocks, *A* and *B*, to the corners of a box as in Fig. 194. To these blocks fasten two slender wooden rods or strips of whalebone with disks fastened to the ends, so that the disks shall move close to and parallel with each other when the rods are vibrated. Cut a narrow slit in each disk as shown, and vibrate the rods both at the same time. Look through the opening in the slits at some bright light. The vibrations will combine, giving a curve similar to that in Fig. 193, if the ratio of vibrations is 6 : 8.

231. Manometric Flames. — The optical method devised by König, to which he has given the name of *manometric flames*, consists of bringing the condensations and rarefactions of sound waves to act upon a gas flame and regulate its height, and of observing the effect in a revolving mirror. The principle of the apparatus is shown in Fig. 195, and the complete form in Fig. 196. A wooden or metal box is divided into two chambers, *A* and *B*, by an elastic diaphragm *D*. Two pipes open into *B* and one into *A*. The pipe *C* brings in gas, which is burned as a small, round flame at the top of the tube *E*. The pipe *H* opens into *A* and conveys the sound waves made before its open end at *M*. If a condensation strikes *D* it bends toward *B*, making that chamber smaller, increasing the pressure, and making the flame burn higher at *E*. If a rarefaction strikes *D*, the chamber *B* is made larger, the density is decreased, and the flame

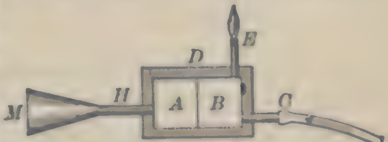


Fig. 195

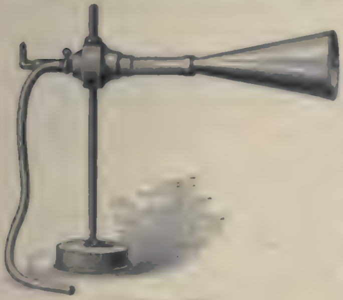


Fig. 196

drops down to a shorter one. These changes follow one another so rapidly that the eye cannot detect them unless the image of each flame is separated from the others. This can be done in two ways: first, by turning the eye quickly and throwing the line of sight across the flame, when the images will be separated in the eye; and second, by the use of a revolving mirror. If the mirror is turned while the flame is burning steadily, its reflection seen in the mirror will be a band of light as in Fig. 197, but if a simple tone is sung into the mouth *M*, the rise and fall of the flame will show itself as a succession of pointed reflections of equal height, leaning in the direction opposite to the rotation of the mirror, as in Fig. 198. If now the octave of this note is sung, the reflection will have twice the number of points. If the note sung is made up of vibrations of different lengths, the reflection will show a compound form in which smaller waves are impressed upon the fundamental.

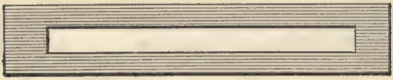


FIG. 197

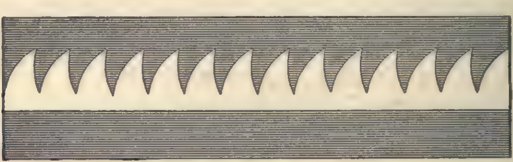


FIG. 198

EXPERIMENT 108. — Sing the notes of the scale before the mouthpiece, calling each note *O*. Notice the change for each pitch. Sing the same scale, calling the notes *do*, *re*, *mi*, etc. Can you tell a simple tone from a compound one?

232. Sensitive Flames. — The air in a tube may be thrown into sound vibrations by means of a small flame.

Experiment 109. — Fix a tube about a meter long and 2 or 3 cm. in diameter in a vertical position. Get a piece of glass tubing 30 cm. long and 5 mm. in diameter and draw one end down nearly to a point, leaving a small hole. Attach to the other end of this tube a rubber tube leading to a gas supply. Turn on the gas and light it, regulating the flame to a height of about 2 or 4 cm. Thrust the small tube within the large one as in Fig. 199, and a point will be reached where the flame will begin to flutter and the large tube will begin to sing. Examine this flame in a rotating mirror, and it will be found to give a result like Fig. 198.

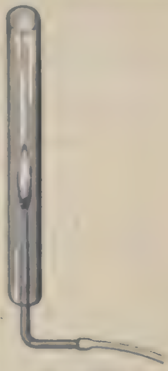


Fig. 199

Note. — All experiments with the vibrating flames and rotating mirror will give the greatest satisfaction if carried on in a dark room.

Experiment 110. — Procure a glass tube about 8 mm. in diameter and about 20 cm. long and draw it down to a small jet. Bend this tube at right angles and fasten it to a small board with a wire staple. Place this under a tripod covered with wire gauze, as shown in Fig. 200. Turn on the gas and light it above the gauze. Regulate the position of the glass tube and the pressure of the gas until you have a flickering blue flame, broad at the base and pointed at the top. Place over this a tube 5 cm. in diameter and of almost any length, and it will at once break into a loud musical note. Compare the pitches given by tubes of different lengths.

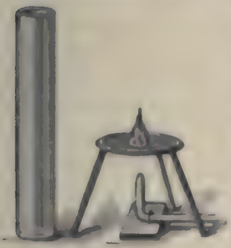


Fig. 200

233. The Phonograph. — One of the most successful instruments for recording the vibrations of sound is the *phonograph*, which was invented by Edison. The essential features, in its modern form, consist of a cylinder of specially prepared wax upon which the vibrations of a diaphragm are recorded by means of a fine metal point or chisel attached to the diaphragm. The waves of sound throw the diaphragm into vibration, this sets the point in motion, and as the wax cylinder is rotated the point cuts a series of spiral grooves. These grooves are made up of minute indentations which correspond to the condensations and rarefactions of the sound waves. By means of a special form of point which takes the place of the cutting tool, and follows in the groove which it has cut, the sound can be reproduced with remarkable fidelity to the original.

234. Limit of Audibility. — It is a matter of common knowledge that the range of voice differs for different people, one person singing bass, another tenor, another alto, and another soprano. There is a somewhat similar range in hearing, some ears being more sensitive to the high pitches and some to the low.

Experiment 111. — Procure a Galton's whistle, which consists of a small brass whistle with a rubber bulb at one end and a screw for adjusting the pitch at the other. Press the bulb when the screw is nearly out, and a rather low whistle will be heard. Turn in the screw a little, and sound again. The pitch is higher. In this way make the pitch steadily higher and higher, and it will be found that first one member of the class and then another will be unable to hear the whistle, showing that the limit of hearing in the high notes has been reached.

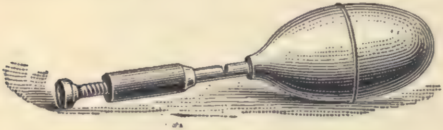


Fig. 201

PRACTICAL QUESTIONS AND PROBLEMS

1. A certain string, 80 cm. long, vibrates 128 times per second. What must be the length of a similar string stretched with the same tension to vibrate $213\frac{1}{3}$ times?

2. A certain string, 1 m. long, vibrates 256 times per second. How long must a similar string stretched with the same tension be, to vibrate 128 times? How can this number of vibrations be produced without using so long a string?

3. The *do* of the scale of *C* is made by a string 4 feet long. Where must the movable bridge be placed to give the *sol* of the same scale?

4. The pitch given by a certain string is *c* when the spring balance by which it is stretched reads 1.5 lb. What will the balance read when the string sounds *e*?

5. In what respect does the sound produced by a wooden organ pipe 1 m. long differ from that given by a metal pipe of the same length? In what respects is it the same?

6. If an open organ pipe must be 6 feet long to produce a certain note, how long must a closed pipe be to give the major third of that note?

7. Are open or closed pipes used for the low notes of church organs? Why?

LABORATORY WORK

1. To one of the prongs of a tuning fork fasten a fine thread of white silk, using for the purpose a bit of beeswax. To the other end of the thread tie a light paper scale pan. Place gram weights (or small shot) in the scale pan until, on holding the fork horizontal with its side downward, and striking it with the cork hammer, the cord will be thrown into a wave form. Find the relation between the number of loops and the weight in the pan. Change the weight and see whether the number of loops will be changed. Hold the fork with the edge downward and vibrate. Does the same weight give the same number of loops as before?

2. Using the vibrating plates of § 228, work out ten different figures and make drawings of them. Locate the places where the bow was drawn and the finger placed in each.

3. Make a number of resonators of different sizes, like Fig. 202, using Manilla paper pasted together or fastened with shellac for the cylindrical part and fastening smaller tubes into cardboard disks for the ends. Both the small tubes forming the ends are open, and when in use *A* is turned toward the sounding body while *B* is connected by a rubber tube with one side of a manometric flame, — as with the tube *H* in Fig. 195. By using the different sizes of resonators it can be shown that, while a certain sound will put some of the flames in vibration, it will have no effect whatever upon others.

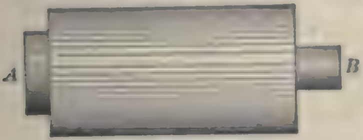


FIG. 202

By supporting a number of these resonators in a frame and having each one attached to its own manometric flame, a very interesting study can be made of the quality of different voices.

4. On the opposite sides of a baseboard about 4 cm. thick and 40 cm. square, fasten two uprights 102 cm. long above the upper surface of the base. Fix a crosspiece to the top of these. Bore a hole in the middle of this and fit a handle so that it will turn snugly. Make a lead disk 10 cm. in diameter and 2 cm. thick, and through the middle drill a hole 5 mm. in diameter. Suspend this by three cords as in Fig. 203, and at the point *A* tie these three cords to two others which run through the holes *B* and *C* in the crosspiece and then through a hole in the handle *H*. Wind a ring of copper wire *R* about the two cords, so that it can be slipped up or down and unite the two into one, as *RA*. Now place a glass plate on the baseboard, and sift sand upon it from a tin flour dredge. Select a glass rod or tube that will slip easily through the hole in the disk, and make one end small and rounded in a Bunsen flame. Put the rod through the disk; then draw the disk back and release it so that it will vibrate across the base in the direction *DE*. The disk swings as a pendulum from the points *C* and *B*, and the rod traces a straight line in the sand. Vibrate again in a direction *FG*, at right angles to *DE*. The rod will again trace a straight line, swinging from the point *R*. Now draw the disk aside midway between these directions, and the rod will trace a curve which will be the result of combining the two motions, and the form of which will depend upon the relative lengths of the two pendulums, *i.e.* of the points *K* and *R* from the middle of the lead disk.

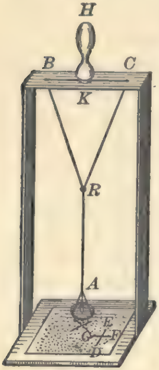


Fig. 203

The distance of *K* from the middle of the disk can be kept at 1 m. by turning the handle *H*; and by making the distance of *R* from the middle of the disk such that the short pendulum vibrates three times while the long one vibrates twice, the curve corresponding to the combination of the notes *sol* and *do* is obtained. If the times of vibration are as 2 : 1, the curve will represent the combination of a note and its octave. By applying the law of the pendulum for length and time of vibration, the length of the short pendulum can be easily found for most musical intervals.

5. Procure a tin tube about 30 cm. long and 1 cm. in diameter, and close one end of it. Drill a row of fine holes around the tube near the closed end. Connect the other end with a gas supply and light the gas as it comes from the row of holes. Fix a second tin tube 10 cm. in diameter and more than a meter long in a vertical position and introduce the smaller tube with its flame into the lower end of the larger tube. Explain the result. Fit a second large tube upon the end of the first. Why is there a change of pitch?

6. Select a piece of small glass tubing and draw it to a point in the Bunsen flame, leaving a fine opening. Connect the other end, by means of a rubber tube, to a gas supply, and if you have the right size of hole in the tube, and the right pressure of gas, you will get a long line of flame, as in *A* (Fig. 204), that is just on the point of flaring. Make any kind of a sharp sound, and the flame will at once drop down to the form of *B*, and will keep flaring in that form as long as the sound continues. A shrill whistle, the rattle of keys, or any hissing sound will produce the same effect, showing that this is a very *sensitive* form of flame.

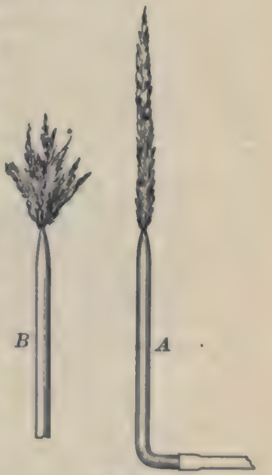


FIG. 204

Does the rapid change in pressure at the mouth of the tube, caused by the waves of condensation and rarefaction due to the high pitch of these sounds, explain the action of the flame? Test this flame by giving a shrill whistle outside of the room when the door is closed.

CHAPTER VII

HEAT

I. TEMPERATURE AND ITS MEASUREMENT

235. Heat a Form of Energy. — The *kinetic theory of heat*, which is the expression of modern ideas on this subject, considers that the molecules of all bodies are in a state of rapid vibration, and that any increase of the rapidity of this motion, from whatever cause, increases the heat of the body, while the heat is decreased if this velocity is diminished.

Heat is a form of molecular energy which may be produced by other forms of energy, and is itself convertible into other forms.

236. Temperature. — The terms "hot" and "cold" are purely relative. Whether one body is hotter or colder than another depends upon whether it can itself impart heat to the second body, or receive heat from it. The condition of a body in this respect is called its *temperature*, and depends upon the relative rapidity of vibration of its molecules.

When the molecular kinetic energy of a body is doubled, its temperature is doubled. If one body is put into contact with another, the one that has the higher temperature will lose some of its heat, and the one that has the lower temperature will gain heat, until they will both finally come to the same temperature.

Temperature must not be mistaken for quantity of heat.

A cup of hot water taken from a pailful will have the same temperature, but will contain very little heat in comparison with the water in the pail.

237. The Physical Effect of Heat upon Bodies. — There are two main results that may come from applying heat to a body. One is a change in its volume, and the other is a change in its physical condition.

Experiment 112. — Make a piece of apparatus like that shown in Fig. 205, as follows. Set two upright posts in a baseboard. Bore in each post, near the top, a hole large enough to take a brass wire ⅛ in. in diameter. Fasten one end of the wire to one post by a screw in the top and let the wire pass loosely through the other post. Connect a battery and electric bell with the wire, and let the other end of the circuit be connected with a thin brass spring just beyond the movable end of the wire. Adjust the spring carefully and bring the flame of a Bunsen burner against the wire. The heat will expand the wire, which will make contact with the spring, when the electrical circuit will be completed and the bell will ring. Remove the flame; the wire will contract, the contact will be broken, and the bell will stop ringing.

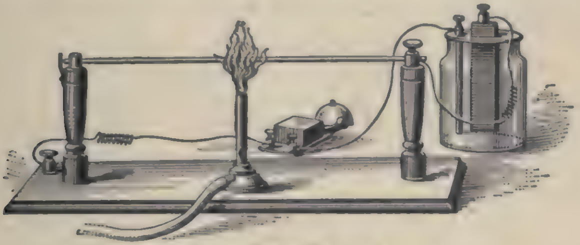


Fig. 205

Experiment 113. — Place a piece of beeswax on a tin plate and hold it over a source of heat. What change in its physical condition is produced?

Experiment 114. — Fit to the mouth of a test tube a rubber stopper with a single hole. Thrust a piece of glass tubing, about 30 cm. long, through the stopper. Fill the test tube with water and push in the stopper until the water stands at some point as *A* (Fig.

206). Take the tube by the end and lower the test tube into a beaker of hot water. The first effect is that the water in the small tube will drop to *B*. What is the cause of this? The second effect is that the water will then begin to rise and will finally run over the top *C*. Why?

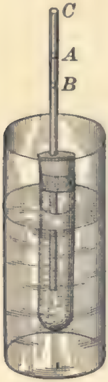


FIG. 206

EXPERIMENT 115. — Use the test tube, rubber stopper, and small glass tube used in Experiment 114. Introduce a short column of water into the middle of the small tube, and, having the test tube dry, hold it in a horizontal position and push in the stopper. Clasp the test tube in the hand and watch the position of the water index. Does air expand on being heated?

The above experiments show that solids, liquids, and gases expand on being heated. The amount of this expansion depends upon the change in temperature.

238. Measurement of Temperature. — The *thermometer* is an instrument used for measuring temperature. The principle employed is that of the expansion of bodies when heated. The most common form is the mercury thermometer, which consists of a glass tube with thick walls and a small bore, blown into a bulb for holding the mercury at one end.

239. Filling the Thermometer. — The glass tubes are blown with a cup on the end, as in Fig. 207, so that when the air has been partly driven from the bulb by heating it, a small quantity of mercury put into the cup will be driven into the bulb by the atmospheric pressure when the bulb cools. By repeatedly heating the bulb and filling the cup, the bulb can be entirely filled. The mercury is then heated until it boils, and when the tube is entirely filled it is sealed at the top and left air-tight.

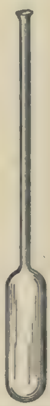


FIG. 207

240. Determining the Fixed Points. — The two fixed points of a thermometer are the freezing and boiling points of water. The freezing point is determined by placing the bulb and part of the stem in snow or finely crushed ice, contained in a vessel perforated at the bottom, so that the water can drain away. The point at which the mercury comes to rest is marked as the *freezing point.* Care should be taken that the ice comes in close contact with the bulb and that the mercury does not come above the ice.

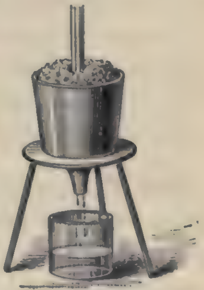


FIG. 208

The *boiling point* is fixed by boiling pure water in a vessel and suspending the thermometer in the steam. The bulb should be at least an inch above the water and the dish should be tall enough so that the mercury will come only just above the stopper by which it is supported. Whenever the steam is coming briskly from the escape pipe and the mercury has ceased to rise, the end of the column is marked as the boiling point, provided the barometer reads 760 mm. at the time. A tall cylinder with double walls (so that the thermometer may be surrounded by steam of uniform temperature) is the best form for the boiler.

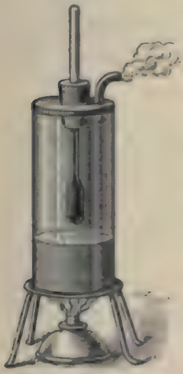


FIG. 209

241. Graduating the Scale. — The freezing and boiling points of water are invariable, as standard points should be, and the graduation is based upon them. Before accepting a tube from which to make a thermometer, the maker carefully calibrates it to find whether it is of practically uniform diameter throughout its length, and if it is found to be variable, it is rejected. Assuming that it is uniform, equal increases of temperature will cause equal amounts of elongation of the mercury column in any part of the tube; hence, when the kind of scale has been decided upon, the length between the freezing and boiling points is divided into equal parts, called degrees.

242. Thermometric Scales. — The scales in most general use in this country are the *Centigrade*, or hundred-degree scale of Celsius, which makes the freezing point of water zero (0°) and its boiling point 100°; and the *Fahrenheit*, which makes the freezing point 32°, the boiling point 212°, and puts the zero 32° below the freezing point. In both scales, readings that are below zero are designated by the minus sign, as – 10° C. The Fahrenheit scale is the one in common use in the United States, but the Centigrade has been adopted for scientific work on account of its greater convenience. Unless otherwise mentioned, the Centigrade scale will be used in this work.

243. Comparison of Centigrade and Fahrenheit Readings. — Since the Centigrade scale has 100 degrees between the fixed points, and the Fahrenheit 180, it is evident that 100° C. = 180° F., and hence 1°C. = $\frac{9}{5}$°F., and 1°F. = $\frac{5}{9}$°C. When the reading of one scale is to be transformed into the equivalent reading on the other, the differing positions of the zero point must be taken into account, as well as the different values of the degrees. The following formulas may be used:

$$C = \tfrac{5}{9}(F - 32^\circ) \qquad (46)$$

$$F = \tfrac{9}{5}C + 32^\circ \qquad (47)$$

The relation between these readings can be seen by reference to Fig. 210.

Readings between the fixed points will be + in both scales, but while all readings below the freezing point on the Centigrade are −, those between 32° and 0° on the Fahrenheit are +.

For very low temperatures alcohol is used instead of mercury, which freezes at −38.8. Mercury boils at 358°, so that for very high temperatures a metallic thermometer or the air thermometer is used.

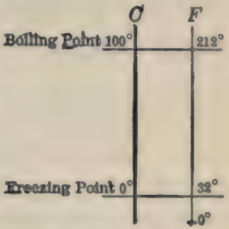


Fig. 210

244. The Air Thermometer. — A simple form of *air thermometer* can be made by thrusting the tube of an air thermometer bulb through a rubber stopper with two holes, and fitting this stopper to a test tube or bottle half full of colored water. A scale along the side is used for reading the height of the water column, which is introduced by driving out a few bubbles of air from the bulb by heating it. When the air cools the water will rise in the stem. The position of the water column is due to the pressure of the air as well as to the temperature, so that it does not correspond directly with the readings of the mercurial thermometer.

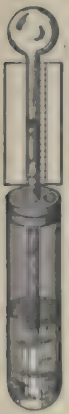


Fig. 211

245. Displacement of the Fixed Points. — After the thermometer is made and the fixed points are marked, the mercury frequently rises higher than zero at the zero temperature and reads above 100° as the boiling point of water. This is due to a gradual change that takes place in the volume of the bulb. If the tubes have been drawn and filled a year or two before they are graduated the error is less, but a thermometer should be frequently tested to know what correction is necessary in reading.

246. Absolute Zero. — In experimenting upon the effect of heat upon gases it is found that if the temperature of a gas is reduced from 0° to – 1°, its volume is reduced by $\frac{1}{273}$ of its volume at zero. This is true of a reduction of one degree anywhere along the scale. Hence it is held that at a temperature of – 273° the gas would have no molecular kinetic energy and no heat. This point, – 273° C., is taken as *absolute zero.* On the absolute scale the temperature of melting ice or freezing water would be 273°, and of the boiling point of water 373°.

247. Metallic Thermometers depend upon the unequal expansion of two metals. A convenient form is made by fastening the two metals in the form of a spring having on the outside the one whose rate of expansion is the greater. One end of the spring being fixed, the other end acts upon a pointer which marks off the temperature on a circular scale on the face of the instrument. This scale is calibrated by comparison with a standard mercury thermometer.

PRACTICAL QUESTIONS AND PROBLEMS

1. Suppose there is a change of 14° C. in the temperature, what will be the equivalent change in Fahrenheit degrees?

2. If the change in Fahrenheit degrees is 37, what is the equivalent change in Centigrade degrees?

3. Change the following readings to Fahrenheit readings: 23° C.; – 4° C.; – 23° C.

4. Change the following readings to Centigrade readings: 69° F.; 23° F.; – 8° F.

5. What temperature will give the same reading on both the Centigrade and Fahrenheit scales?

6. Thermometer A has for its highest reading 100° and thermometer B has 360.° If the bulbs are of the same size and the length is the same in both, which should have the smaller bore? On which can a slight change of temperature be read the more accurately?

7. Mercury freezes at – 38.8° C.; what is the absolute temperature of its freezing point on the Centigrade scale?

8. What is the absolute temperature of freezing water in Fahrenheit degrees? How many Fahrenheit degrees is absolute zero below the Fahrenheit zero?

9. The Réaumur scale is marked 0° at the freezing point of water and 80° at the boiling point. Find expressions for changing a Réaumur reading to the equivalent Centigrade and Fahrenheit readings.

10. Suppose you need to take the temperature of a liquid quickly; would you use a thermometer with a large bulb or one with a small bulb?

LABORATORY WORK

1. Test the zero mark of the laboratory thermometers by the method shown in Fig. 208, and make a record of each.

2. Test the boiling point of the same thermometers by the method of Fig. 209, and make a record. Keep these records to be used as corrections for future readings with these instruments.

3. After the tests for the boiling point are made, pour more water into the vessel so that it will surround the bulb. Boil the water and take the readings. Is the temperature of the water the same as the temperature of the steam?

4. Take the temperature of boiling water first in a glass dish and then in a copper dish. Is the boiling point the same in the two vessels?

5. Dissolve salt in the water and boil again. Is the reading the same as before?

These experiments show that the temperature of boiling water depends upon the character of the vessel and the purity of the water. The temperature of the steam from water boiling at the same pressure is constant.

6. Test the uniformity of the bore in a thermometer tube as follows: Hold it horizontally by the stem and give it a short, sharp jerk in the direction of its length. This will separate a short thread of the mercury. Beginning with the lower end of the thread near the upper end of the remaining mercury, read the position of both ends of the thread on the scale, using a reading glass and estimating the tenths of a division. Move the thread towards the upper end by a short jerk, and read again. Take, in this way, 20 or 30 readings of each end of the thread and tabulate your results as indicated in this table. With this table as data, construct a curve showing the relation between the length of the thread and the position of its middle point on the scale.

No.	Lower End	Upper End	Middle	Diff.
1	3.2°	22.8°	13°	19.6°

II. Production and Transmission of Heat

248. Sources of Heat. — The principal sources of heat are the *sun; the interior of the earth; mechanical sources* such as *friction*, *impact*, and *compression*, in which work is changed into heat; *chemical action*, in which chemical energy is transformed into heat; and *animal heat*, which, being due to oxidation, is only a form of chemical action.

That the sun is a source of heat needs no proof, while the experience of miners working in deep mines proves that there is internal heat, the temperature rising as the distance from the surface increases.

249. Friction. — There are many familiar examples of the heating effects of friction. The train of sparks that fly from a sleigh runner as it passes over a stone, and the sparks that come from a car wheel when the brake is applied, both show that great heat is generated by the friction; for the sparks are burning steel. The hands are warmed by rubbing. A match is set on fire by friction, and a piece of wood in a turning lathe is charred when the corner of another piece is held against it.

250. Impact. — When two bodies meet in collision the effect of the blow is to increase the rate of vibration of the molecules, and hence to raise the temperature of the bodies.

Experiment 116. — Rest one end of an iron rod upon an anvil and strike it a dozen blows with a heavy hammer. Observe any change in the temperature.

251. Compression. — When a gas is suddenly compressed there is a corresponding sudden rise in its temperature.

Experiment 117. — Close the rubber tube leading from a large bicycle pump with a clamp. Raise the piston the full height and suddenly force it down. Observe any change of temperature that has taken place in the lower end of the pump.

252. Chemical Action. — Many chemical combinations give rise to heat. The most familiar of these is combustion. The burning of a match or of coal is an example of the heat derived from chemical action.

Experiment 118. — Into a test tube pour 4 c.c. of water. Pour slowly into this water 1 c.c. of concentrated sulphuric acid. The acid and water were both at the temperature of the room. Place a thermometer in the mixture. What change has taken place?

253. The Transmission of Heat. — When two bodies are brought in contact with each other, each communicates a part of its molecular energy, or heat, to the other. If the two bodies are of the same temperature, each receives as much as it imparts and there is no change in the temperature of either. If, however, the body A is of a higher temperature than the body B, it gives more heat than it receives, and its temperature is lowered by an amount which is dependent upon the difference between these temperatures; while the body B has its temperature raised, and we say heat has been transmitted to it. Heat can be transmitted in three ways — by *conduction*, by *convection*, and by *radiation*.

254. Conduction. — Experiment 119. — Hold in the hand one end of a copper wire 10 cm. long, and heat the other end in the flame of a Bunsen burner. The end in the flame will become red-hot, and in a short time the end in the hand will become uncomfortably warm.

This method of transmission, by which the heat is transferred from molecule to molecule along the body, is called *conduction*.

If the same experiment is made with a glass tube, the glass can be melted to within 4 or 5 cm. of the fingers without burning them, while a stick can be burned to the very fingers without harm.

These three examples illustrate bodies that are *good*, *medium*, and *poor* conductors of heat. A good conductor feels either warmer or colder than a poor conductor of the same temperature. This is due to the fact that it conveys its heat to the hand, or takes heat from the hand, more readily than the poor conductor. Liquids as a class are poor conductors of heat.

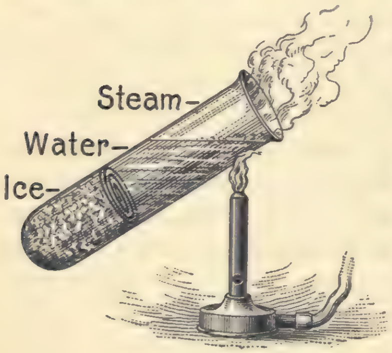


Fig. 212

Experiment 120. — Put some pieces of ice in the bottom of a test tube. Fasten them there with a coil of wire. Pour in water until the tube is nearly full, and then hold it over a Bunsen burner so that the heat will be applied at a point covered by the water. In this way the water in the upper part of the tube may be boiled while there is ice in the bottom only a few centimeters away.

255. Convection. — The specific gravity of liquids and gases diminishes as the temperature increases, and as the molecules are free to move there is set up an ascending current wherever any part of the liquid or gas is heated above the rest. These currents are called *convection currents.*

EXPERIMENT 121. — Fit a rubber stopper with two holes to the mouth of a thin glass flask. Through these holes thrust two glass tubes about 8 cm. long, making the end of one nearly even with the top of the stopper, and the other nearly even with the bottom. Fill the flask with colored water and heat it. Put in the stopper and sink the flask in a large glass of cold water, as in Fig. 213. Convection currents will be set up by the warm water coming out of one tube while the cold water goes in the other. In which will the cold water go?

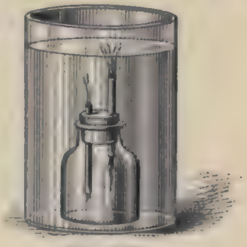


FIG. 213

A very useful practical application of convection currents in liquids is that of heating houses by hot water. In this method the water is heated by a boiler placed near the lowest point of the circuit of pipes. The heated water rises through the pipes and is returned again to the boiler when cooled.

256. Convection in Gases. — Air that is in contact with a heated surface becomes itself heated, and since an increase in temperature causes a corresponding decrease in the specific gravity of a gas, a convection current is set up. This can be shown by lighting a piece of touch-paper and holding it over a piece of heated metal, when the smoke will rise with the currents of air.

NOTE. — Touch-paper is made by dipping filter paper or blotting paper into a solution of saltpeter. When dry it will burn without flame but will give off smoke freely.

EXPERIMENT 122. — Set a short piece of candle in a saucer and light it. Set over it a chimney from a student lamp. Pour water enough into the saucer to prevent air going into the chimney from the bottom, and the candle will burn but a short time, and then will go out. Why? Cut a piece of tin of the shape shown in (*a*) in

Fig. 214, and put it down the chimney with the notch resting on the top. The candle will now go on burning. Why? Examine the air on both sides of the tin division, by the smoke from touch-paper.

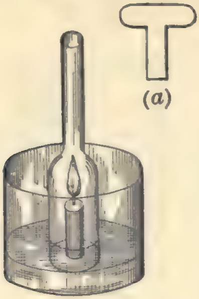


FIG. 214

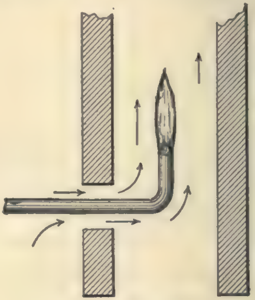


FIG. 215

257. Ventilation. — The above experiment shows the need of renewing the air in order to support combustion. It also shows how this is secured by means of convection currents. A room may be ventilated by burning a gas flame in a flue in the wall, as in Fig. 215. Heated air being lighter than cold, the air in the flue is forced upward by the greater downward pressure of the air in the room.

258. Radiation of Heat. — The third method by which heat may be transferred from one body to another is by radiation. If the open hand is held in front of a stove, the radiant energy sent out by the fire is received on the hand and it becomes warm, though the air may not feel warm. If a screen is placed between the stove and the hand the radiation is cut off. The earth receives heat from the sun in the form of radiant energy. This comes from the sun as a wave motion in the ether which fills all space. When these vibrations are received by a body they set its molecules into more rapid vibration, which raises the temperature of the body, and we say the body receives heat.

259. Laws of the Radiation of Heat.

I. *Radiation takes place in straight lines.* This law is true in a *homogeneous* medium only, that is, in one that has the same physical structure throughout.

II. *Radiation takes place through a vacuum as well as in the air.* This results from the nature of the radiation, for the medium by means of which the radiation takes place is the ether and not the air. If this law were not true we should receive no heat from the sun.

III. *The intensity of radiant heat is proportional to the temperature of the source.*

IV. *The intensity is inversely proportional to the square of the distance.*

Suppose *A* (Fig. 216) is a source of heat. Suppose this to be at the center of a hollow sphere of which the radius is *AB*. All the heat radiated in a given time will be received on the surface of this sphere. If now this sphere is replaced by a larger one, of which the radius is *AC*, the same amount of heat will be received by the surface of the larger one as was received by the surface of the smaller one in the same time. But the areas of these surfaces are directly proportional to the square of their radii ; hence the quantities received on equal amounts of surface of the two spheres will vary inversely as the square of the distance from the source. A similar course of reasoning will prove the law of intensities.

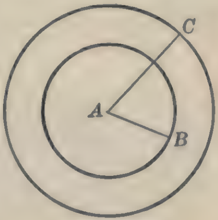


FIG. 216

260. The Reflection of Radiant Heat. — Experiment proves that radiant heat is reflected in accordance with the following laws :

I. *The incident and reflected rays are in the same plane.*

II. *The angle of reflection is equal to the angle of incidence.*

EXPERIMENT 123.—Pour a little water in a flask, fit a rubber stopper with two holes to it, and through one of them pass the stem of an air thermometer A (Fig. 217). Place a red-hot iron ball in a support *B*. Set up a screen *S*, to cut off all direct radiation toward *A*. Place a mirror at *M*, and a position can easily be found where the heat will be reflected upon *A*. This will heat the air and drive out part of the water from the stem. The bulb of the air thermometer should be blackened to secure the best results.

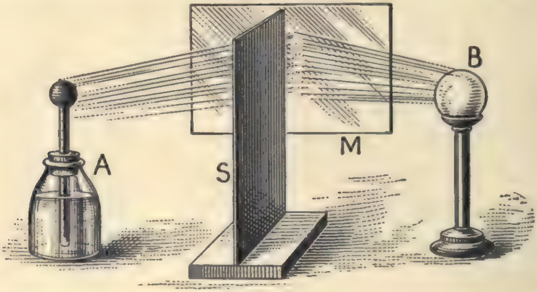


FIG. 217

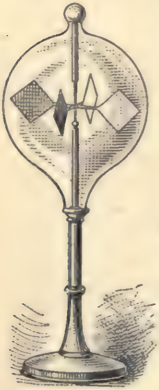


FIG. 218

261. The Radiometer is an instrument used to detect radiant heat. It consists of a glass bulb inclosing two arms of aluminum crossing each other at right angles and carrying at each end an aluminum disk. One side of each disk is coated with lampblack while the other is bright. These arms are fastened horizontally to a vertical shaft which can rotate with them, being supported by a projection at the bottom of the bulb. When these disks are subjected to the action of radiant heat they set up a rotation, the velocity of which is dependent upon the intensity of the heat received.

This apparatus can be used to show the reflection of heat as follows:

EXPERIMENT 124.—Procure two concave mirrors *M* and *M′*. In the focus of *M* place the radiometer and in the focus of *M′* place an iron ball heated nearly to redness. Do not place the ball so near to the radiometer that there will be any rotation due to direct radiation. When the ball and radiometer are in the foci of their respective mirrors, the radiometer will set up a brisk rotation due to reflected radiation.

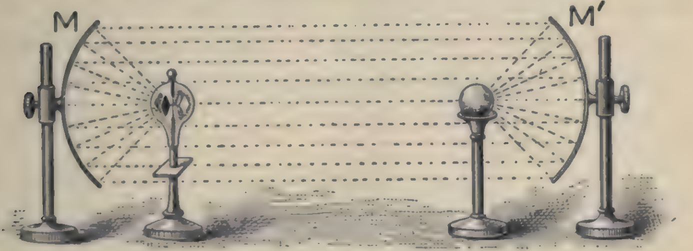


FIG. 219

EXPERIMENT 125.—Make a light-tight box, large enough to hold a radiometer. Heat a flat piece of cast-iron or brass nearly to a red heat and fasten it to the inner face of the door of the box. Put the radiometer into the box and close the door. Leave it closed for about a minute and on opening it the radiometer will be found to be rotating. Is it heat or light that produces the rotation?

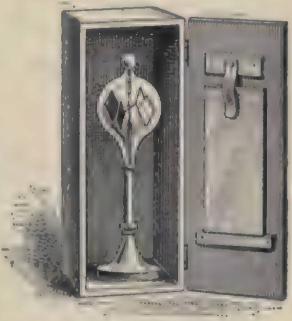


FIG. 220

262. Radiating and Absorbing Powers.—The radiating power of a heated body depends upon its temperature and the character of its surface. A body with a smooth, brightly polished surface has a low radiating power, while if it is of the same material but with a dull surface its radiating power is greater. Bodies that absorb heat readily are good radiators and poor reflectors. The power of absorption depends somewhat upon color. This can be shown by placing two pieces of cloth upon the snow, one black and the other white. It will be found that when the sun shines upon them the black piece will absorb heat and melt its way into the snow, while the white will not.

263. Selective Absorption. — The extent of the absorption depends, in some substances, upon the temperature of the source of heat.

Experiment 126. — Set the radiometer in front of a fish-tail gas flame so near that it will rotate briskly. Place a pane of glass between them. Nearly all the radiation will be absorbed and the rotation will nearly stop. Set the radiometer in the sunshine. After it is in motion hold the glass plate between it and the sun. Does it stop?

This fact, that glass will permit the radiation from the sun to pass through, but will absorb that from bodies of much lower temperature, is of great importance, since the radiation from the sun enters our rooms through the windows and heats them, while the heat from stoves and radiators cannot pass out.

This radiation that comes from the sun and passes through the glass is called *luminous heat.* That which is absorbed by the glass and comes from bodies of comparatively low temperature is called *nonluminous heat.*

Substances like rock salt, which permit radiant heat to pass through them readily, are called *diathermanous*, while those like glass, alum water, etc., that absorb radiant heat, are called *athermanous.*

Experiment 127. — Place a flat battery jar between the radiometer and the sun. Does the rate of rotation change? Fill the jar with water. Is there any greater change? Repeat with alum water, and salt water. Which is the most diathermanous?

The vapor of water in the air absorbs nonluminous heat to a great degree. Experiments by Tyndall show that the absorptive power of air containing the average amount of vapor is over 70 times that of dry air. The effect of this is to permit a large share of the radiation from the sun to come through and warm the earth during the day, because it is luminous heat, but to prevent the heat of the earth from radiating into space at night.

PRACTICAL QUESTIONS AND PROBLEMS

1. What is the cause of a "hot box" on a railway car?
2. Explain the lighting of a match.
3. Why is the handle of a flatiron made of wood rather than of iron?
4. Suppose you have a quantity of hot water which you wish to cool by setting it in a cold room. Would you put it in a tin or a wooden pail? Why?
5. Make a diagram of the walls you would build for an ice house, and explain.
6. What is the effect of double windows on a house? Why?
7. Show by a figure how a house may be heated by a hot-water system.
8. Do the same for a hot-air system, and state the advantages and disadvantages of both systems.
9. Explain the origin of winds.
10. Why is it hotter in the sunlight and colder in the shade on the top of a mountain than in a low valley?
11. What is the result of using a glass fire screen?
12. In sunny days in the winter dead leaves, or any other dark-colored bodies blown upon the surface of the snow, soon melt their way below the surface. Why?
13. Explain the effect of the glass in a greenhouse upon the heat that comes from the sun, and upon that that comes from the inside of the house.

LABORATORY WORK

1. If there is a turning lathe in your laboratory, turn a cylinder of soft pine, and then hold a small hardwood stick upon the surface

until you have *burned* several rings upon the pine. What does this show?

2. Select a number of wires of different metals, such as copper, iron, brass, German silver, etc., and fit them in holes drilled in a brass ring. Cover them with a thin layer of paraffin and support the ring so that the flame of a Bunsen burner can be passed through it. Watch the melting of the paraffin, and when it has melted nearly to the end of the first wire, remove the flame and measure the distance melted on each wire. Arrange the metals used in the order of their conductivities.

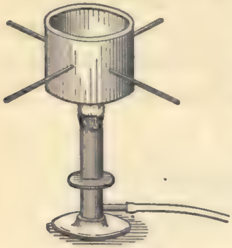


FIG. 221

3. Fill a tall glass jar with hot water colored with aniline dye. Hold the corner of a piece of ice in the surface of the water and observe the resulting current.

4. Get two tin boxes of the same size, cut a hole in the top of each, and insert in it a rubber stopper carrying a thermometer. Paint one of the boxes with lampblack and leave the other bright. Fill them with water of the same temperature and then set them out in the bright sunshine for a half-hour. Read the thermometers and explain.

5. Fill the same boxes with hot water. Set them in a cool place for a half-hour. Read the thermometers and explain.

6. Light a fish-tail burner and at a distance of 1 m. place a radiometer. Count the number of revolutions per minute. Move it 5 cm. nearer the flame and again count the revolutions. Repeat, moving the radiometer 5 cm. nearer each time, until it is so near the flame that you can no longer count the revolutions. From the result of this experiment make a curve, laying off distances from the flame along the horizontal axis, and number of revolutions per minute along the vertical axis. This gives a very satisfactory curve if the radiometer is a good one.

III. EXPANSION AND VAPORIZATION

264. The Measurement of Expansion. — (*a*) *Solids.* — It was proved in Experiment 112 that when the temperature of solids increases, they expand; but that experiment gives little idea of the amount of this expansion. There is, however, a definite relation between a change in the temperature of a body and its corresponding expansion, — a relation which may be represented by the formula

$$L' = L(1 + Kt). \qquad (48)$$

In this formula L is the length of the body at zero; L' its length at $t°$; t its temperature; and K the *coefficient of linear expansion*, or the amount of expansion per unit of length for a change of one degree in temperature. To determine the value of this coefficient for metals requires very accurate apparatus and most careful experimental work. An approximate determination may be made, however, by the use of simple apparatus, such as is shown in Fig. 222.

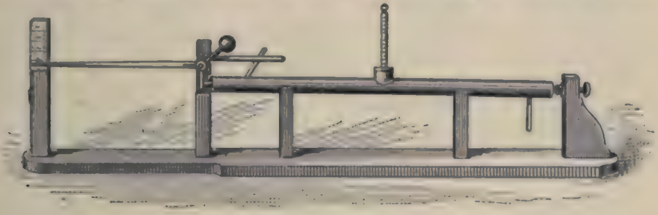


FIG. 222

The largest part of this is a brass tube through which passes from end to end a bar of the metal to be tested. Near each end of this tube is a smaller one through which steam can be passed. The metal bar is fastened at one end and at the other it acts against the short arm of a lever, the long arm of which acts as a pointer. A thermometer at the middle of the tube determines the temperature. Readings are taken first when ice-cold water is circulating through the tube, and again when the tube is filled with steam. The real expansion can be calculated from the values of the scale readings and the relative lengths of the lever arms. When we know the real expansion for a change of 100 degrees we can easily find the amount of expansion per unit length for one degree, and this is the coefficient of linear expansion. The values of this coefficient for various substances are given in this table.

Pine	.00000608
White Glass	.00000861
Platinum	.00000884
Cast Iron	.00001125
Tempered Steel	.00001239
Copper	.00001718
Brass	.00001878
Aluminum	.00002313
Mercury	.00018180
Ice	.0000640

265. Effects of Expansion in Solids. — The difference in temperature between the coldest winter days and the hottest days of summer is enough to make a perceptible change in the length of long pieces of metal, such as wires. Telephone and telegraph wires sag more in summer than in winter. Suspension bridges, like the Brooklyn bridge, are several inches higher in the middle in midwinter than in summer. Wagon tires are put on while hot, and on cooling contract and hold the wheel firmly together. Bridge work and steam boilers are put together with red-hot bolts, so that the parts may be more firmly held together when the bolts are cool.

The effect of expansion may be observed in the filament of an incandescent lamp. On turning on the current the filament will be seen to twist even before it is red-hot, and it will not stop until it is incandescent.

266. The Measurement of Expansion. — (*b*) *Liquids.* — The use of liquids, such as mercury and alcohol, in thermometers, depends upon their expansion. Since the liquid in this case is inclosed in glass, it is not the real expansion of the liquid, but its apparent expansion, that we use.

Experiment 128. — Select two test tubes as nearly of a size as possible. Fit them with rubber stoppers of the same size, and through each stopper fit a glass tube 20 cm. long and about 3 mm. inside diameter. Fill one of the test tubes with water and the other with alcohol, pushing in the stoppers until the liquids rise in the tubes to the same height. Lower both test tubes at the same time into water at 70° and observe the position of the liquids in the tubes. Do they expand equally?

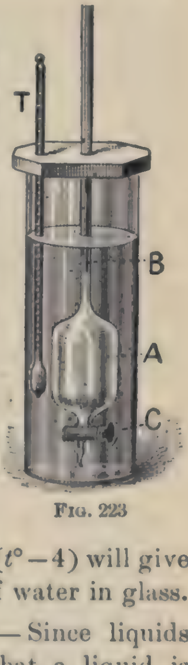


Fig. 223

The coefficient of the apparent expansion of water in glass may be determined by the apparatus shown in Fig. 223. A piece of glass tubing *A* is fused at the upper end to a small glass tube *B*, and at the lower end has a stopcock *C*. This tube holds 100 c.c. of water at 4°, and the small tube is graduated to read thousandths of a cubic centimeter. After being filled to the zero mark with water at 4°, the tube is put into a tall beaker and the water is slowly heated. The temperature is read by the thermometer *T*, both when the water is heating and when it is cooling, and the average readings of the tube *B* are taken. The amount of the expansion divided by the product of $100 \times (t° - 4)$ will give the coefficient of the apparent expansion of water in glass.

267. Effects of Expansion in Liquids. — Since liquids expand on being heated, it is evident that a liquid is lighter when it is warm than when it is cold. An important application of this principle is made in heating buildings with hot water. By this method the water is heated in one part of the system of pipes and on rising passes through the radiators, heats them, and descends again to the heater.

268. The Measurement of Expansion. — (c) *Gases.* — The expansion of air can be shown, and its coefficient approximately determined, by the following experiment:

EXPERIMENT 129. — Place the bulb and most of the stem of an air thermometer below the surface of ice-cold water in a tank. When it is cooled to zero, place it entirely below the surface of the water, with the tube in a horizontal position. Siphon out cold water and pour in warm until the temperature is 60°. This will expand the air, which will bubble out of the end of the tube. Take the temperature when the last bubbles come out, and then put ice in the dish until the water is again at zero. Water will now pass into the bulb to take the place of the displaced air. Wipe the outside of the bulb and stem dry, and weigh. Fill the bulb and stem full of water at zero, and weigh. These two weights, compared with the weight of the bulb when it is full of air, will give the coefficient of expansion.

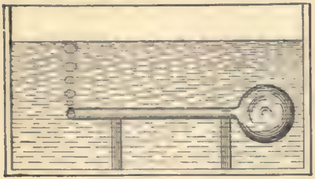


FIG. 224

Experiment shows that the coefficient for air and other gases is $\frac{1}{273}$, or nearly .003665. This means that a volume of 273 c.c. of air at 0° would become 274 c.c. at 1°, and 288 c.c. at 15°, provided the pressure remained unchanged.

269. The Law of Charles. — The relation between temperature and volume in gases is shown by the Law of Charles as follows:

Under a constant pressure the volume of a given mass of gas is proportional to its absolute temperature.

270. Effect of Expansion in the Air. — The effect of heat upon air may be seen in the currents that are set up near a heated surface. The air next the surface becomes warmer and lighter, and cooler air displaces it. This sets up an ascending current over the heated area, and a horizontal current at near-by places. If this heated surface is an extensive tract of the earth, the result will be the setting up of violent winds toward it.

271. Changes of Physical Condition. — If, when the temperature is several degrees below zero, a piece of ice is brought into a warm room, its temperature rises until it is at zero, and its volume increases. If now more heat is applied to it, it melts to a liquid, then heats to 100°, and then boils away. In the course of this process there has been one change of the body from a solid to a liquid, and another from a liquid to a vapor. A similar change of physical condition can be brought about with most solid bodies if only the proper change of temperature can be had. A piece of iron can be changed to the liquid form, but in order to do this a temperature of 1500° must be reached.

272. Fusion. — The change from a solid to a liquid as a result of the application of heat is called *fusion*, or melting. The temperature at which a solid melts is called its *melting point*. The *laws of fusion* are as follows:

I. *Every solid having a crystalline structure begins to melt at a certain fixed temperature that is always the same for that substance if the pressure is constant.*

II. *The temperature of a melting solid remains unchanged from the time melting begins until the body is entirely melted.*

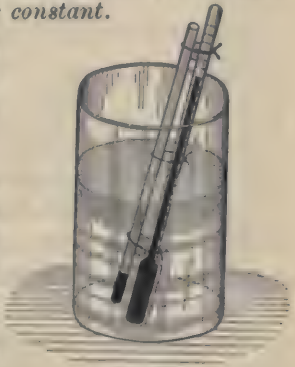


FIG. 225

EXPERIMENT 130. — Draw down the end of a glass tube until its outside diameter is not more than 1 mm. Melt some beeswax in a watch glass and draw the small end of the tube full by suction. Let this cool, and tie the tube to a thermometer in such a position that the wax will come opposite the bulb. Place them in a beaker of warm water (Fig. 225), apply heat from a Bunsen burner, and read the thermometer just as the wax melts. Remove the burner and let the bath cool. Read the thermometer just as the wax solidifies, and take the mean of the two readings for the melting point of the wax.

TABLE OF MELTING POINTS

Alcohol	−130.50°	Lead	335°
Mercury	−38.8°	Silver	954°
Ice	0°	Copper	1054°
White wax	65°	Iron	1500°
Sulphur	114°	Platinum	1775°

273. Solidification is the reverse of *fusion*, and takes place when a liquid is cooled below its melting point. The temperature at which any substance solidifies is the same as the melting point, and in some substances, as water and mercury, this temperature is called the *freezing point.* Every liquid on solidifying gives off an amount of heat that is equal to the heat required to melt it. The freezing point of vegetables is a little lower than the freezing point of water. For this reason pans of water are sometimes placed in vegetable cellars, so that by its freezing it may give out heat enough to keep the air above the freezing point of the vegetables.

274. Vaporization.—When heat is applied to water its temperature is raised, which means that the velocity of its molecules is increased. As they strike against the surface of the water many of them force their way through this surface and pass into the air, where they exist as molecules of water vapor. The number of molecules that pass into the air increases with their velocity or temperature. When the temperature is below the boiling point the process is called *evaporation.* When it is at the boiling point the process is called *ebullition* or *boiling.*

275. Laws of Evaporation.

I. *Evaporation increases with the temperature.*

II. *Evaporation is directly proportional to the surface of the liquid.*

III. *Evaporation is inversely proportional to the pressure upon the liquid.*

IV. *Evaporation decreases as the air becomes saturated.*

Evaporation takes place even at very low temperatures. A block of ice left for a few days in a place where the temperature is below zero, will lose a considerable amount by evaporation. Wet clothes hung out on a cold winter day will freeze at once, but will soon become dry.

Air is said to be *saturated* with moisture when it will hold no more at that temperature. If the temperature is now raised, more evaporation can take place, but if it is lowered, condensation will take place.

276. The Dew Point. — EXPERIMENT 131.— Pour ether into a test tube until it is half full, and put a thermometer into it. Bend a tube at right angles and place in the test tube as in Fig. 226. Connect the short end with a long rubber tube and blow gently through the ether. The ether will evaporate and the temperature will rapidly fall. Watch the surface of the lower end of the test tube and take the reading of the thermometer when moisture first appears on the outside. Now stop blowing through the ether, and its temperature will rise. Take a second reading of the thermometer when the moisture disappears. The average of the two readings will be the *dew point.*

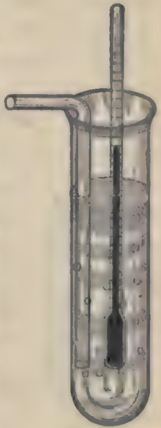


FIG. 226

In connection with the above experiment the temperature of the air should be taken by another thermometer. If the difference in the readings of the two thermometers is great, it shows that the air is far below the point of saturation, but if this difference is little, it shows that the air is nearly saturated, and that a slight fall in the temperature would cause moisture to be deposited.

Fogs, *clouds*, *rain*, and *snow* are examples of the results of lowering the temperature of the air below the dew point. The most oppressive days in summer are those in which the air is nearly saturated with water vapor.

277. Boiling.—If a quantity of fresh water is placed over a source of heat the first effect will be the gathering of air bubbles on the sides of the dish. This comes from the air dissolved in the water. After a time these bubbles break away from the sides and bottom and rise to the surface. Soon bubbles of steam are formed which rise to the top. All this time the temperature of the water has been rising, but soon a point is reached when the steam is formed very rapidly and rises to the surface with considerable violence. The temperature now stops rising and the liquid is said to *boil*.

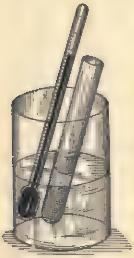


FIG. 227

EXPERIMENT 132.—Heat water in a beaker to 60° and *remove the flame*. Fill a test tube half full of ether and put it, together with a thermometer, into the hot water, as in Fig. 227. Determine the boiling point of ether in this way.

NOTE.—A flame must not be brought near the ether, as its vapor is very inflammable.

EXPERIMENT 133.—Make the same experiment with alcohol and find its boiling point. Does the alcohol boil if you heat the water to only 60° at first?

EXPERIMENT 134.—Fill a round-bottomed flask half full of water. Boil this over a Bunsen burner, and when the steam is coming freely from the neck remove the burner and put a stopper in the mouth of the flask. Invert the flask in a ring support, as shown in Fig. 228, and pour cold water over it. This will condense the vapor above the water and reduce the pressure upon its surface. As a result the water will begin to boil vigorously, showing that if the pressure is reduced the boiling point is lowered.

This effect of pressure upon the boiling point is seen upon the top of a high mountain, where water boils at so low a temperature that food cannot be cooked by boiling. A change of altitude of approximately 560 ft. makes a difference of one degree Centigrade in the boiling point. Advantage is taken of this effect in the making of sugar, where vacuum pans are used to evaporate the solution without burning it. In the extraction of glue from bones and hides the pressure is increased and the boiling point correspondingly raised.

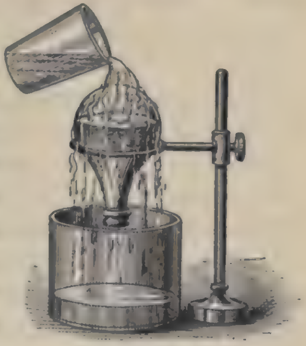


FIG. 228

278. The Spheroidal State. — Whenever water is thrown upon a very hot metallic surface, a condition called the *spheroidal state* is set up. The effect of the heated surface is to vaporize a little of the liquid, so that the remainder does not rest directly upon the metal, but upon a cushion of steam. This by its constant movement keeps the liquid in rapid vibration. If the metal surface cools and the liquid comes in contact with it, a sudden production of steam is the result. Steam boiler explosions have resulted from the water in the boiler getting low, and then cold water being suddenly turned on after the boiler had become red-hot above the water line.

EXPERIMENT 135. — Place a smooth tin or brass plate upon a tripod and heat it with a burner. Drop a few drops of water upon it with a pipette. After the spheroidal condition is set up, remove the flame and let the plate cool. What occurs when the water touches the plate?

279. Condensation of Vapors.—The condensation of a vapor to a liquid is brought about by either lowering its temperature, or increasing its pressure, or both. Since every liquid has its own boiling point, it is possible to separate a liquid from substances which it holds in solution by boiling the solution and condensing the vapor. This process is called *distillation*.

The essential difference between vapors and gases is one of temperature and pressure. Some liquids exist in temperate climates as liquids, while in tropical climates they are gases. Ether is an example. If a gas is subjected to great pressure, and at the same time has its temperature reduced, it reaches a point at which it becomes a liquid. The air is now liquefied by this method, and forms a colorless liquid with a temperature of – 191° C. at the atmospheric pressure. In other words, the boiling point of liquid air at the ordinary pressure of the atmosphere is – 191° C.

EXPERIMENT 136.—Arrange apparatus as shown in Fig. 229. Pass cold water in at the lower end of the water jacket and let it run out at the top. Put a mixture of equal parts of alcohol and water in

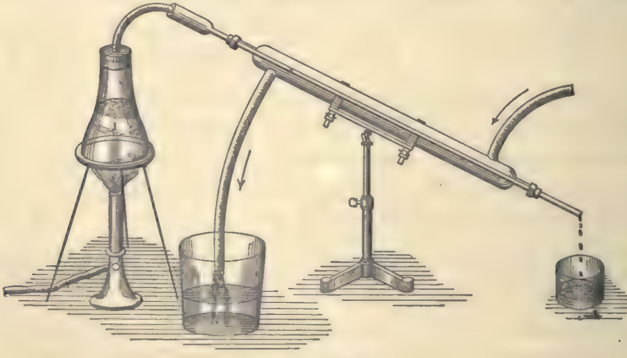


FIG. 229.

the flask. Boil it until about a third of the mixture is condensed in the beaker. Remove the flame and test the distillate by setting it on fire. Test the mixture remaining in the flask in the same way.

280. Fractional Distillation. — Since every liquid has its own boiling point, it is quite possible to separate a mixture of several that have different boiling points, by the process called *fractional distillation.* When crude petroleum is distilled, as soon as the boiling begins it is kept at that temperature until no more distillate comes over. This most volatile part of the oil having been removed, the temperature is now raised a few degrees, boiling begins again, and the petroleum is kept at that temperature as long as any vapor comes over; and so on until nothing is left but a thick sirup. The product that comes off last is the highest grade of all.

PRACTICAL QUESTIONS AND PROBLEMS

1. How much will a brass box 10 ft. long expand on changing from 0° to 24°?

2. Why is platinum wire always used when a wire is to be fused into a glass tube?

3. Suppose the point of a Bunsen flame to touch the middle of the bottom of a Florence flask filled with water. Make a drawing of the convection currents that will be set up.

4. What will be the volume of a mass of air at 23°, if its volume at 0° is 625 c.c.?

5. Show by a figure the direction of the trade winds in the northern hemisphere, and explain the reason for this direction.

6. Explain the bursting of water pipes on freezing.

7. What weight of water will be evaporated from the surface of a lake 100 ft. square in 10 hours, if an experiment shows that evaporation is going on at the rate of .003 in. in 30 minutes?

8. Why is sea water distilled before being used in the boilers of steamships?

9. What is the effect of placing a beaker of water at 80° under the receiver of an air pump and then exhausting the air?

10. The Dead Sea is 1306 feet below the sea level. At what temperature will water boil there? Below or above 100°?

11. Mount McKinley is 20,464 feet above the sea level. At what temperature will water boil there?

LABORATORY WORK

1. Prepare two rods of the same length and diameter, one of steel and one of brass. Fit them to the apparatus shown in Fig. 222, and determine the coefficients of expansion.

NOTE. — The student must not expect to get results that are very accurate, but the difference in the expansion of the two metals will be plainly shown.

2. Determine the expansion of water in glass by the apparatus shown in Fig. 223. Apply heat slowly and take two sets of readings, one on heating and one on cooling. Take the average of the two readings as the true reading. Make a curve from the results obtained, with expansion laid off horizontally and temperatures vertically.

3. Determine the melting point of butter, lard, paraffin, and beeswax.

4. Wrap the bulb of a thermometer with a thin coat of cotton. Read the temperature. Wet the cotton with water and after a few minutes read again. Put on a dry piece of cotton and wet it with ether and read again. What is the effect of evaporation?

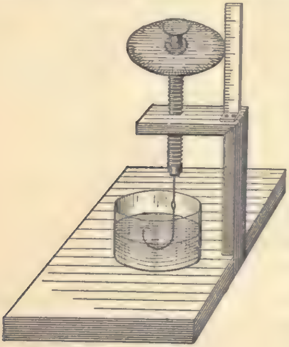


FIG. 230

5. Using a hook gauge as shown in Fig. 230, measure the evaporation (*a*) in the room, (*b*) in the draught of an open window, (*c*) in the open air. The hook is moved up and down by the micrometer screw to which it is fastened. The point of the hook should be lowered beneath the surface of the water and then raised until it touches this surface from below. On looking across the surface of the water as on a mirror, the slight distortion of the surface that is caused by the hook touching it can be seen very readily.

6. Pour 100 c.c. of water into a flask and then dissolve in it 10 g. of salt. Distill the solution, keeping the first 10 g. of the distillate in one beaker, the second in another, and so on. Test each distillate for salt by tasting. Pour out the solution left in the flask. Wash the flask thoroughly and redistill the first 10 g. in which you can taste the salt. What is the effect of redistilling?

IV. CALORIMETRY

281. The Measurement of Heat. — In order to measure the quantity of heat that is given to a certain amount of water, two things must be considered: the mass of the water and the change of the temperature.

Since there are different units of mass and different thermometric scales, several thermal units are possible. The two most important are defined as follows: the quantity of heat required to raise 1 g. of water through 1° C. is called a *calorie;* the quantity of heat required to raise 1 lb. of water through 1° F. is called a *British thermal unit* (B.T.U.). French engineers also use a unit 1000 times as great as the calorie, *i.e.*, 1 kg. of water is the basis instead of 1 g. The measurement of the heat used in changing either the temperature or the physical condition of a body is called *calorimetry*.

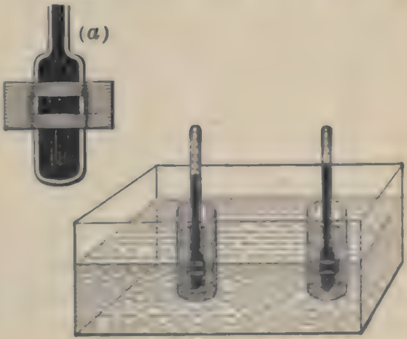


FIG. 231

282. Specific Heat. — EXPERIMENT 137. — Select two beakers of the same size and fill one of them two thirds full of water. Pour the same weight of alcohol into the other. Make a stirring fan for each by cutting two slits in a rectangle of thin copper, and fitting it on the bulb of a thermometer as in (*a*) in Fig. 231. Put the stirring fans in the beakers and read. Set both beakers in a tank of hot water, at 75°, say. Stir the contents of the beakers by twirling the thermometer stems between the thumb and finger, and read the thermometers at the end of every minute. Which liquid heats the more rapidly? The experiment can be made more accurate by using beakers of such sizes that the surface of each covered by the liquid inside is the same.

If, in the above experiment, the liquids have the common temperature 18° at the beginning of the experiment, it will be found that when the water reads 50° the alcohol will read about 70°. If no correction were needed for the heat given to the beakers it would read 71.5°. This means that the same heat that will raise a certain mass of water through 32° will raise an equal mass of alcohol through 53.5°.

The ratio between the quantity of heat required to raise the temperature of a certain mass of any substance one degree, and the amount required to raise the same mass of water one degree, is its specific heat; or, *the number of calories required to change the temperature of 1 g. of a substance 1° C., is its specific heat.*

The specific heat of various substances is given in the following table:

TABLE OF SPECIFIC HEAT

Water	1.000	Aluminum	0.214
Ice	0.502	Iron	0.113
Steam	0.480	Copper	0.094
Ether	0.516	Mercury	0.033
Alcohol	0.620	Lead	0.031

283. The Measurement of Heat. — A convenient method for measuring the specific heat of a body is the *method of mixtures.* This method depends upon the fact that when two bodies that are at different temperatures are put together, the temperature of one will fall and that of the other will rise until they have reached the same temperature. It also depends upon the principle that the heat absorbed by the cool body in heating is exactly the amount given out by the hot body in cooling.

EXAMPLE. — Two pounds of fine shot at 90° were poured into one pound of water at 15°, and the resulting temperature was 20°. What was the specific heat of the shot?

The quantity of heat given out by the shot in cooling = mass × change in temperature × specific heat. The quantity of heat absorbed by the water in heating = mass × change in temperature × specific heat, or

$$Mts = M't's', \qquad (49)$$

hence, since the specific heat of water = 1,

$$1 \times 5 \times 1 = 2 \times 70 \times s$$

$$\text{or } s = \frac{5}{140} = .036$$

284. Latent Heat of Fusion. — If heat is applied to a beaker of crushed ice, it will be noticed that while the ice is being melted the temperature of the resulting water is the same as that of the ice, *i.e.* zero. The effect of the heat is not to change the temperature, but to change the physical state from solid to liquid.

The number of heat units required to melt one unit of mass of a substance without raising its temperature is the *latent heat of fusion* of the substance. When the substance solidifies, the same amount of heat will be given out.

EXPERIMENT 138. — Pour 500 c.c. of water at 80° into a beaker, and into this put 150 g. of cracked ice as dry as possible. Stir the ice until it is melted and take the resulting temperature of the water. It will be found to be about 43°.

The latent heat of fusion of ice can be found from the above experiment as follows: The heat given out by the 500 c.c. of water is used in melting the ice and raising the resulting water to 43°.

$$\text{Heat given out by water} = 500\,(80° - 43°) \times 1 = 500 \times 37$$
$$= 18500 \text{ calories.}$$

$$\text{Heat taken up by ice in melting} = 150 \times \text{Latent Heat} = 150\,L \text{ calories.}$$

$$\text{Heat taken up by resulting water} = 150 \times 43 \times 1 = 6450 \text{ calories.}$$

$$\therefore 150\,L + 6450 = 18500$$

$$150\,L = 12050$$

$$L = 80\tfrac{1}{3}$$

This means that it takes as much heat to melt a pound of ice as it would to raise one pound of water from 0° to about 80°.

285. Latent Heat of Vaporization. — When heat is applied to a beaker of water its temperature will rise until the boiling point is reached. After this no further increase in the temperature will take place, however rapid the boiling. By continuing the experiment the water can all be changed into vapor. The number of heat units required to vaporize one unit of mass of a liquid without changing its temperature is its *latent heat of vaporization.* When the vapor changes to a liquid the same amount of heat will be given out. Experiment has shown that the latent heat of vaporization of water is 537. This means that the heat required to boil away one pound of water is 5.37 times as much as is required to raise its temperature from zero to 100°.

286. Curve of Heat Effects. — A very effective way of showing the relation between the heat units applied and the effects produced is that used in Fig. 232. This shows by a curve the relation between the heat units and these changes when heat is applied to 1 g. of ice at −18° until the latter is changed into steam at 120°. Horizontal distances represent heat units and vertical distances represent change of temperature.

Since the specific heat of ice is .5, $Mts = 1 \times 18 \times .5 = 9$ calories required to raise the ice to zero. 80 calories will be required to melt it; $1 \times 100 \times 1 = 100$ calories to raise the water to 100°; 537 calories to vaporize it; and, since the specific heat of steam is .48, $Mts = 1 \times 20 \times .48 = 9.6$ calories to raise the steam to 120°. The total calories of heat applied will be the sum of these amounts, or 735.6 calories.

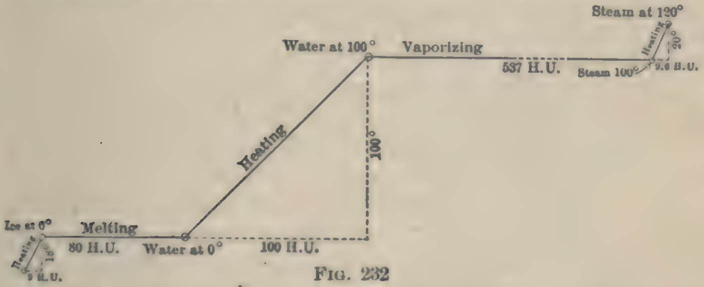


FIG. 232

A careful study of this curve will be of great assistance in understanding the relation between heat units, specific heat, and latent heat, and will help in the solution of problems that include these quantities.

PRACTICAL QUESTIONS AND PROBLEMS

1. What are some of the results of the high specific heat of water? Are they beneficial or not?

2. Suppose a room has the temperature − 1°; what would be the result of allowing water to freeze in it?

3. 4 kg. of water at 60° is mixed with 6 kg. at 21°. Find the temperature of the mixture.

4. Equal weights of water at 90° and mercury at 18° are mixed together. What is the temperature of the mixture?

5. A piece of nickel at 100° was dropped into an equal weight of water at 0° and the resulting temperature was 9.8°. Find the specific heat of the nickel.

6. What mass of water at 60° will just melt 5 kg. of ice at 0°?

7. How much water at 90° must be mixed with 10 lb. of ice at 0° to melt the ice and raise the resulting water to 16°?

8. What quantity of water at 80° will change 10 lb. of ice at – 14° into water at 5°?

9. What quantity of steam at 100° will be required to melt 16 kg. of ice and heat the resulting water to 24°?

10. How many calories will be required to melt 8 g. of ice at zero, raise the temperature of the resulting water to 100°, and vaporize it? Make a curve to show this.

11. Lead melts at 335°. How much heat must be applied to 8 g. of lead at 0° to raise it to the melting point? What would be the result of applying the same quantity of heat to 8 g. of water at 0°?

12. How many calories would be given out by 10 g. of water at 45° in cooling to zero and then freezing?

13. The end of a steam pipe is put into a beaker containing 500 g. of water at 0°. How much steam must be condensed to raise the temperature of the water to the boiling point?

14. If 500 g. of copper filings at a temperature of 150° is poured into 205 g. of water at 0°, what will be the resulting temperature?

15. 100 g. of aluminum is heated to 90° and placed in 300 g. of alcohol at 16°; what is the resulting temperature?

In all the above problems no account has been taken of the temperature of the containing vessel. It is evident that this must be taken into account.

16. If 500 g. of boiling water is poured into a copper beaker containing 300 g. of ice at 0°, what will be the resulting temperature if the beaker weighs 125 g.?

17. A roll of sheet lead weighing 650 g. is suspended in boiling water. It is then transferred to a glass beaker weighing 70 g., in which there is 300 g. of water at 18°. What will be the resulting temperature if the glass has a specific heat of .177?

18. A sufficient quantity of heat is applied to 180 g. of ether to change its temperature from zero to the boiling point (37°). What effect would the same amount of heat have upon 180 g. of water at zero?

LABORATORY WORK

1. Select two glass beakers of the same size and put in one 300 g. of hot water and in the other 300 g. of cold water. Take the temperature of each, and quickly pour the contents of both into a third beaker. Take the temperature of the mixture. Consider this experiment preliminary and repeat, having previously brought the beaker which is to hold the mixture to about the temperature the mixture had in the first experiment, so that none of the heat may go to warming the beaker. Is the resulting temperature a mean between the other two?

2. Suspend, by means of a strong thread, a roll of sheet lead in a beaker of water. Apply heat until the water boils. Put in a second beaker sufficient cold water to cover the lead. Take the weight and temperature of this water. Transfer the lead quickly from the boiling water to the cold and take the temperature after the lead and the water have come to a common point. Weigh the lead and the beaker and from the data determine the specific heat of the lead.

3. Weigh a beaker. Fill it two thirds full of water and weigh again. Heat this to 70 or 80 degrees. Crush some ice fine, getting it as dry as possible by putting it between the folds of a towel. Take the temperature of the water and immediately put in the dried ice. Stir it thoroughly, and when the ice is all melted and the temperature is constant, read it. Weigh the beaker and contents again to find the weight of ice added. From the data thus obtained determine the latent heat of fusion of ice.

4. Arrange apparatus as in Fig. 233. Weigh the water in *A* and take its temperature. Place the burner under *C* and boil the water. Do not put the tube leading from the trap *B* into *A* until the tube is heated by the steam coming out of the lower end. Boil vigorously for 15 minutes, then remove *A*, take its temperature, weigh it, and from the data thus found determine the latent heat of the vaporization of water.

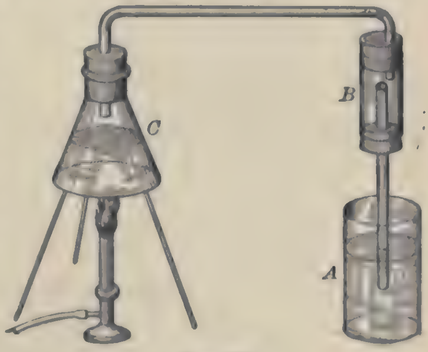


FIG. 233

NOTE.—The heat used in heating the beaker *A* must be included. This is done by finding the *water equivalent* of the beaker — its weight multiplied by its specific heat — and multiplying this by the change of temperature.

5. Determine the *cooling curve* for water by heating a beaker of water to 90° and then removing the source of heat. Read time and temperature simultaneously. The best method is to read the time for every degree of the thermometer. Make the curve by laying off time along the axis of X, and temperature along the axis of Y. This makes a very smooth curve and shows conclusively how the rate of cooling changes as the difference of temperature between the water and the surrounding air diminishes.

V. HEAT AND WORK

287. General Law. — We have seen that friction and percussion both give rise to heat. It is also found that mechanical work of any kind produces heat. The relation between mechanical work and heat was investigated by Dr. Joule, who established the following principle: *The disappearance of a certain amount of mechanical energy produces an equivalent amount of heat.* The converse of this law is equally true: *The disappearance of a certain amount of heat produces an equivalent amount of mechanical energy.*

288. The Mechanical Equivalent of Heat. — The number of units of work required to produce one heat unit is called the *mechanical equivalent of heat.* Dr. Joule's experiments determined that the number of foot pounds of work necessary to heat 1 lb. of water 1° F. is 772, or to heat 1 lb. of water 1° C. is 1390. This is called *Joule's equivalent.* More recent determinations by Dr. Rowland give 778 and 1400 instead.

The method employed by Dr. Joule in his determination was as follows: A cord attached to a weight was run over fixed pulleys and wound around the axis of a wheel, with paddles at the other end of the axle. This was arranged so that on letting the weight fall the paddles were caused to rotate in a known quantity of water in a vessel. The weight multiplied by the distance through which it falls gives the mechanical work, and the mass of water multiplied by the change of temperature gives the heat units. Joule's experiment showed that a 10 lb. weight falling through 77.2 ft. would raise the temperature of 1 lb. of water through 1° F.

Experiment 139. — Place a quantity of water in the flask *A* (Fig. 234). Raise the water to the boiling point, and after it has boiled about a minute remove the flame and put in a rubber stopper with tube as shown in the figure. Replace the flame, and the steam formed by boiling will collect in the flask above the surface of the water and increase the pressure. As this pressure increases it will do work by forcing water out of the tube.

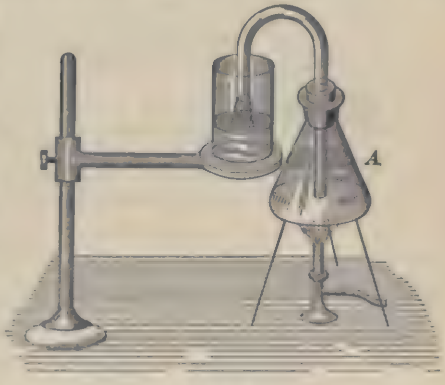


Fig. 234

289. The Steam Engine. — A steam engine is a machine for transforming the pressure and expansive power of steam into work. Since the steam is produced by the application of heat it is in reality a heat engine. So great, however, are the losses in the burning of the coal, the expansion of the steam, and the working of the engine, that the best modern steam engine does not utilize more than 15 per cent of the energy in the coal.

The principle of a simple form of steam engine is shown in Fig. 235. *A* is a boiler connected by a steam pipe *B* with the steam chest *C* through the valve *D*. The live steam passes from the steam chest through the port *E* into the left end of the cylinder, between the cylinder head *F* and the piston *P*. The pressure of this live steam forces the piston to the right, and drives the exhaust steam, on the other side of the piston, out of the port *G* under the slide valve *V*, and out of the exhaust port H, which leads either to a condensing chamber or to the open air.

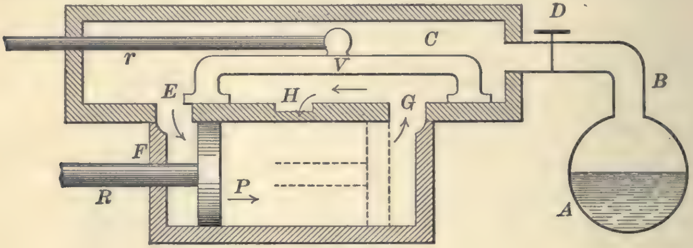


FIG. 235

When the piston has been forced over a part of its stroke, the slide valve will be moved by its rod *r* to the left, closing *E*, and the work done during the rest of the stroke will be due to the expansive power of the steam. By the time the piston has reached the dotted position the slide valve will be moved so far to the left that the live steam will now come into the right end of the cylinder through *G*, and the exhaust steam in the left end will go out of the exhaust port *H*, through the port *E*. The piston rod *R* is attached to a crank arm on the main shaft, and in this way the to-and-fro, or reciprocating, motion of the piston is changed to the rotary motion of the shaft. On the shaft is fixed the fly wheel, a heavy wheel, the momentum of which serves to give steadiness to the engine; and the belt wheel, over which runs the belt by which the motion of the shaft is transmitted to machinery.

If the exhaust steam passes into the open air as it does in the locomotive, the engine is noncondensing, while if it passes into a compartment containing water for condensing the steam, it is a condensing engine.

290. The Energy Stored in Coal. — While we look upon the sun as the present source of the heat received by the earth, we must not forget that in the vast deposits of coal found in the earth, we have a storehouse of the sun's energy in the past, preserved for our present use. Whenever a pound of carbon is burned it gives out 8080 thermal units, and, since the per cent of carbon in anthracite coal is very high, we may say that if we could use without waste all the heat given out by burning one pound of coal to heat water, we could raise 8000 pounds through 1° or we could raise 80 pounds from zero to the boiling point. This carbon in burning unites with oxygen in the proportion of 8 parts of oxygen by weight to 3 parts of carbon, so that to burn one pound of coal requires about $2\frac{2}{3}$ pounds of oxygen. The amount of this energy stored in coal may be seen by considering the fact that the burning of 2.3 tons of coal will carry a heavy passenger engine and loaded train — weighing more than 350 tons — from New York to Philadelphia, a distance of 90 miles.

CHAPTER VIII

MAGNETISM

291. Natural Magnets. — Certain kinds of iron ore have the property of attracting iron. Pieces of this ore when suspended so as to swing freely will come to rest in a direction pointing toward the magnetic north and south, and are called *natural magnets.* The name *magnet* was given because this ore was first found near Magnesia in Asia Minor. The ore is called *magnetite.*

292. Artificial Magnets. — EXPERIMENT 140. — Rub a sewing needle from the middle toward the point across one end of a natural magnet; then rub the other half across the other end of the magnet. Hold one end of the needle near some iron filings. They will be found to cling to the needle. Small bits of iron wire and carpet tacks may also be picked up with it.

A piece of steel that has the property of attracting iron as in the above experiment is called an *artificial magnet.* This name is not a very appropriate one and is used simply to distinguish magnets composed of manufactured iron or steel from natural magnets.

Artificial magnets are made in various forms, as bar magnets, horseshoe magnets, compound magnets, etc.

293. Permanent and Temporary Magnets. — Magnets may be classified according to their property of retaining magnetism. Magnets made of steel have this property to a great degree and are called *permanent magnets*, while those made of soft iron retain very little magnetism and are called *temporary magnets.*

294. Polarity. — EXPERIMENT 141. — Lay a bar magnet upon a table covered with small nails, and then lift it by the middle. It will be found that the nails cling to the magnet, the greater number being near the ends, as in Fig. 236.

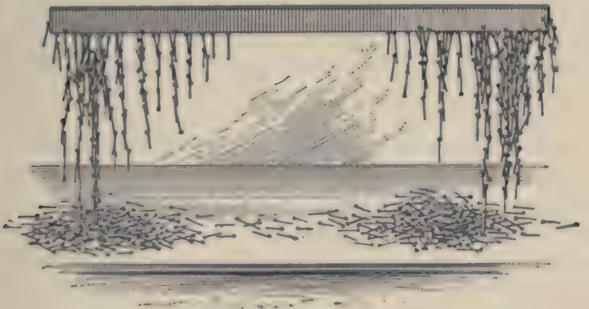


FIG. 236

The two points near the ends where the most nails cling are called the *poles* of the magnet, which is said to possess *polarity*. A body possessing polarity is said to be *polarized*.

EXPERIMENT 142. — Suspend the bar magnet used in the last experiment by a thread attached to its middle point, and after swinging back and forth for a time it will finally come to rest in a direction that is nearly north and south.

It has been agreed to call the end which points to the magnetic north the + or *north pole* and the other the − or *south pole*. The strictly correct names would be *north-seeking pole* and *south-seeking pole*.

FIG. 237

295. The Magnetic Needle is a small bar magnet suspended by a thread or balanced upon a pivot. It is used in many instruments, as in the compass. The direction in which it comes to rest is called the *magnetic meridian*, and that part of the earth to which it points is called the *north magnetic pole*.

Experiment 143. — Magnetize a sewing needle by drawing it across the ends of a bar magnet. Begin the stroke at the middle of the needle and end it at the point, drawing it across the + end of the magnet. Do this a dozen times. Reverse the needle and draw it across the — end of the magnet, beginning at the middle of the needle and ending at the eye. Unravel a fine silk thread, and tie a single strand around the middle of the needle. When you have balanced the needle so that it will hang horizontally, fasten the thread in place by a bit of beeswax or sealing wax, and you have a magnetic needle that will serve for many experiments.

Suspend the needle and find the magnetic meridian. Observe which end of the needle points north, and notice whether or not it is the end that you drew over the north end of the magnet.

Experiment 144. — Make a small bar magnet out of a good-sized knitting needle. In stroking it with the magnet lay it upon a piece of board and stroke it with the + end, from the middle to one end of the needle. Reverse the needle and magnet and repeat. In order to make a strong magnet, the steel must be stroked a great many times. Test it with iron filings and nails.

296. Mutual Action of Magnets.—Experiment 145.—Bring the + end of a bar magnet near the + end of a magnetic needle and note the result. Bring the — end of the magnet near the + end of the needle and observe. Make the same experiment on the south end of the needle.

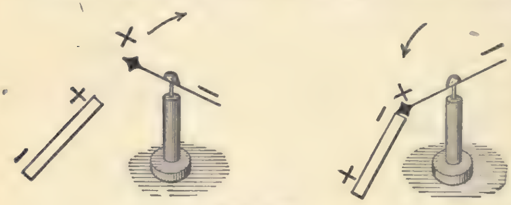


Fig. 238

The results of this experiment may be stated in the following terms : *Like poles repel and unlike poles attract each other.* This law is a fundamental one in magnetism and should be made very familiar.

297. Magnetic and Nonmagnetic Substances. — Experiment 146. — Place on the table a collection of a dozen different materials, — nails, screws, pins, pencils, wire, paper, etc., — and try to pick them up with a magnet. Part of them will be picked up, but upon others the magnet will have no effect whatever.

Those substances that are attracted by a magnet are called *magnetic substances*, while those that are not attracted by it are called *nonmagnetic substances*. Iron, steel, nickel, and cobalt are all magnetic. Some ores of iron are magnetic, while others are not. Nonmagnetic iron ores can be made magnetic by being strongly heated, as in the flame of a blowpipe.

298. Distribution of Magnetism in a Magnet. — EXPERIMENT 147. — Lay a bar magnet upon a table and hold suspended above it the sewing needle magnetized in Experiment 143, passing the needle from end to end. At the middle of the magnet the needle will be parallel to it. This is called the *neutral point*. At other points the needle will dip more or less, in all cases pointing to a pole of the magnet. At two points near the ends the needle stands practically vertical; these points locate the poles.

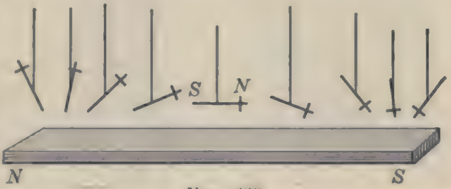


FIG. 239

299. The Magnetic Field. Lines of Force. — The strength of a magnetic field is measured by the number of *lines of force* in a given area, one line of force per sq. cm. meaning a field of unit magnetism. If the like poles of two magnets of equal strength repel each other with a force of one dyne when one centimeter apart, each is called a unit pole. A field of unit strength would act upon such

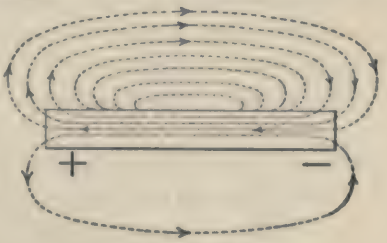


FIG. 240.

a pole with a force of one dyne, and is said to be a field having one line of force per square centimeter. Magnetic lines of force always form closed circuits and take the path of least resistance. By the *direction* of lines of force — shown by the arrows in Fig. 240 — is meant the direction along which a north magnetic pole would be repelled if free to move.

EXPERIMENT 148. — Lay a bar magnet upon the table and cover it with a sheet of white paper. Put over this a glass plate and sift iron filings evenly over it. Rap the plate gently with a lead pencil; the filings will move at every blow, and will arrange themselves in lines that show clearly the direction of the *lines of force.*

The sieve for this experiment can be made by melting the solder that holds on the bottom of a tin can, removing the bottom, and tying over the can, in its place, a piece of thin muslin or cheese cloth.

EXPERIMENT 149. — Hold your magnetized sewing needle quite near the paper used in the last experiment. Notice that it places itself in line with the filings. A magnet only half an inch long, made from a broken needle, will be better for this experiment.

300. Photographic Method of Recording the Lines of Force. — If, instead of the glass plate used in Experiment 148, an ordinary photographic dry plate is used, and the experiment is made in a dark room with a ruby lantern for light, a permanent record may be made. The dry plate is placed upon the magnet, film side up, the filings are sifted upon it, and the plate is rapped with a lead pencil until the position of the lines of force is clearly brought out. The exposure is made by burning a match about a foot above the plate. On developing the plate in the usual way a negative is obtained from which may be made prints showing the position taken by the filings. Fig. 241 gives the magnetic curves in the field formed by a horseshoe and a bar magnet. The mutual action of the poles is shown in the straight lines leading away from the adjacent north poles and in the short curves between the north pole and the adjacent south pole.

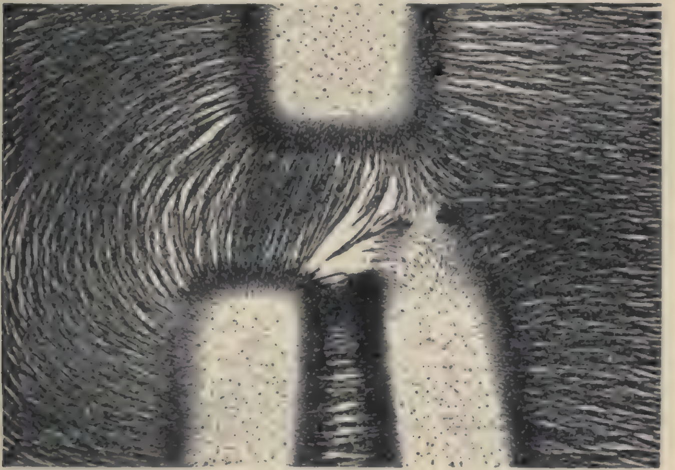


FIG. 241

301. The Magnetic Condition of the Earth. — We have already seen that the + pole of a magnet repels the + pole of a needle and attracts the – pole, and *vice versa.* We have also seen that the needle tends to set itself in the direction of the lines of force, and that a magnetic needle, suspended so as to swing freely, points with its *north* end toward the magnetic *north.* It is evident then that the earth acts as a great magnet, and that the pole toward which the north-seeking end of the needle points, is like the – or south end of a bar magnet. The fact that the north magnetic pole of the earth and the north pole of a magnetic needle are of unlike signs has given rise to some difficulty in giving them names that are scientifically correct; but the name north for the + pole of the needle is generally adopted.

302. Inclination or Dip. — In Fig. 239, we see that in every position but one the needle *dips* toward one of the poles. In the same way a needle that has been balanced horizontally on a pivot and then magnetized, will not remain horizontal, but will dip toward the nearer pole of the earth. The *angle of dip*, that is, the angle the needle makes with a horizontal line, increases as the distance from the magnetic equator increases. At the magnetic equator there is no dip, while at the magnetic poles the needle will place itself in a vertical direction.

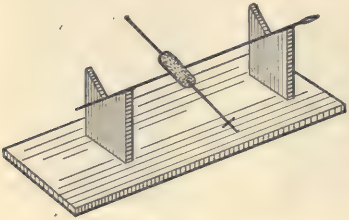


Fig. 242

Experiment 150. — Thrust a knitting needle lengthwise through a very small cork. Put a sewing needle through the cork at right angles to the knitting needle and close to it. Use the small needle as an axis for the large one. Vary the position of the knitting needle in the cork until it comes to rest in a horizontal position when the axis is placed on supports of equal height. Fasten the cork to the needles with melted sealing wax. Magnetize the knitting needle with a strong bar magnet. Place again on the supports, and observe the change that takes place in its position when the + end is turned to the north.

303. The Dipping Needle. — Figure 243 shows a form of needle that is used to determine the dip. It is supplied with two scales: one a fixed scale at the base, and the other a ring from which the position of each end of the needle can be read. Miners use a similar instrument for detecting the presence of magnetic ores.

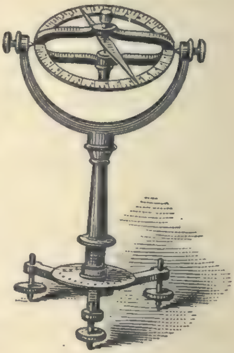


Fig. 243

304. Magnetic Terms. — If AB (Fig. 244), is the position of the dipping needle, the angle CAB is called the *angle of dip*, and if AB represents the magnetic intensity I, AD will represent the *vertical component* V, and AC the *horizontal component* H, of the earth's magnetic attraction. It is evident that a needle attached to a vertical axis can respond only to the action of the horizontal component.

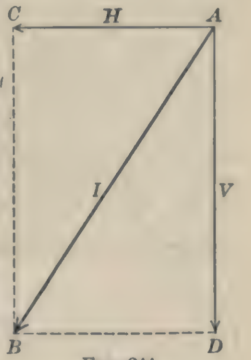


FIG. 244

305. Magnetic Declination. — We have seen that the magnetic needle does not point to the true north. The reason for this is that the north pole of the earth and the magnetic north pole do not coincide. The magnetic north pole is about latitude 70° N., and longitude 96° W.

By reference to Fig. 245, showing the western hemisphere, it is readily seen that in the Eastern states, as in Maine, for example, the needle will point to the west of the true north, while in California it will point to the east of true north. The angle between the direction of the needle at any place, and the meridian at that place, is the *declination*. The value of this angle changes from year to year by an amount which is not uniform, and

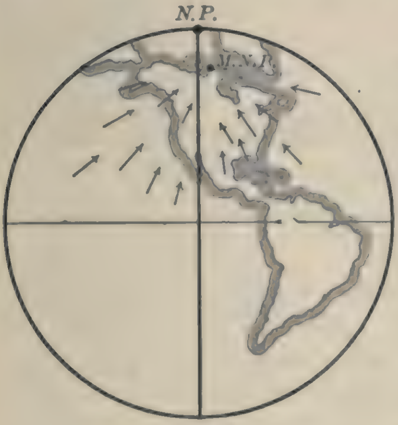


FIG. 245

which is called the *annual variation.* The declination in Maine in the year 1900 was 20° W., while in Oregon it was 20° E.

NOTE. — Mr. Samuel Entriken, a member of the Peary North Greenland Expedition, says that at the most northern point reached by them, the north end of the needle pointed south of west, and that the streamers of the Aurora Borealis centered in that direction.

306. The Agonic Line. — The line connecting all places on the earth's surface where the needle points to the true north is called the *agonic line.* Its position in the United States is shown in Fig. 246. Places to the east of this line have a variation or declination to the west, while places west of the line have a variation to the east. Since the magnetic variation is changing from year to year, it is a matter of great importance in surveying land that the amount of this variation should be known, and records of this change are made and preserved. By comparing these

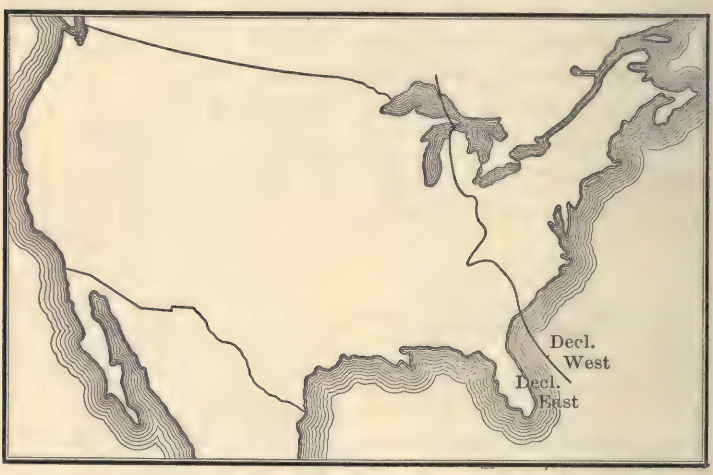


FIG. 246

records it is seen that the declination in places in which it is west is gradually diminishing, while declination to the east is increasing. The present rate of change is about 7 minutes per year.

307. Magnetic Induction. — When a piece of soft iron is put in contact with a bar magnet, it becomes a magnet itself and will attract iron. When a magnet is dipped in iron filings or nails and lifts a number of them attached to one another, each becomes a distinct magnet. This result takes place even if the nail does not touch the magnet, and it is called *magnetic induction.*

Experiment 151. — Place a bar magnet upon a table and at one end, in line with it and about an inch away, put a large nail as in Fig. 247. Bring smaller nails near the end of the large one and observe that it attracts them. Test the end of the nail with the magnetized sewing needle.

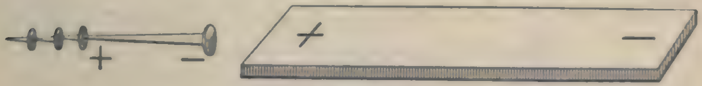


Fig. 247

This property possessed by a magnet — of inducing polarity in magnetic substances that are near to it — is the basis of a great many magnetic phenomena. By the application of this principle, and that of the mutual action of magnets, the action of a magnet upon an iron ball may be explained. Suppose the ball to be at a distance from the magnet, as in (*a*), Fig. 248. The ball is practically beyond the influence

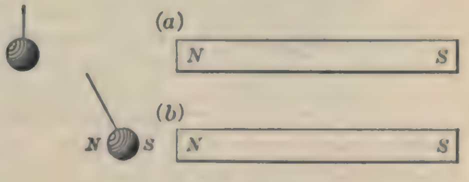


Fig. 248

of the magnet and remains in a neutral condition. When, however, it is brought near the magnet, as in (*b*), induction takes place, and the ball becomes polarized, the side nearest the magnet being *S* and the other side *N*. Now between the *N* of the magnet and the *S* of the ball there is attraction, while between the *N* of the magnet and the *N* of the ball there is repulsion; but as the *S* of the ball is much nearer the *N* of the magnet than the *N* of the ball is, the attraction is much greater than the repulsion, and the ball moves toward the magnet.

308. The Inductive Action of the Earth.—The inductive action of the earth can be shown most strikingly by the following experiment:

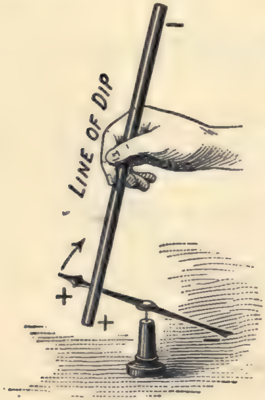


Fig. 249

Experiment 152.—Select a soft iron bar about an inch in diameter and three or four feet long. Holding it horizontally in an east and west line, present its ends successively to the *N* and *S* ends of a magnetic needle. Both ends will attract each end of the needle, showing that the bar is not polarized. Next hold it in the line of dip, with the lower end at the side of the needle and near the north end. The needle will be repelled at once, showing that in this position the bar is polarized. Reverse the bar and make the same test with the needle, and the bar will show that its polarity is reversed. Bring the bar into the first horizontal position and again it will attract both ends of the needle, showing that it is not polarized. Place the bar again in the line of dip and give it one or two sharp blows with a hammer. Now place it in the first horizontal position; and on testing it with the needle it is found to be polarized. Hold it horizontally in an east and west line and give it a few sharp blows; and it will be found to be not polarized.

EXPERIMENT 153.—Test the steel or iron rods about the building for polarity. Most of them will be found polarized, especially if they have been in a vertical position. Test a vertical rod with the magnetized sewing needle. If the upper end of the rod attracts the point the lower end will attract the eye, and *vice versa.* What is the polarity of the lower end of the rod? Why?

309. Molecular Magnets.—If we consider the molecules of iron to be polarized, we can explain this inductive action as follows. When a piece of iron is not polarized or is in a neutral condition, we may suppose that the positions taken by these molecular magnets have no uniform direction, but that their positions are determined by the mutual action they have upon one another. When, however, a magnet is brought near, their mutual action is overpowered by the greater force of the magnet, they assume parallel directions, and the iron becomes a magnet.

EXPERIMENT 154.—Make twenty or thirty small magnets from the mainspring of a watch. Break off pieces a half inch long, magnetize them, and with a strong pointed punch make an indentation in the middle. Make a support for each by cutting out a disk of sheet lead and driving a pin through it to the head. Mount the needles upon these supports, as in Fig. 250. Set these needles upon a board as near as they can be placed without touching one another, and they will take various positions, as shown in the figure. Now bring one end

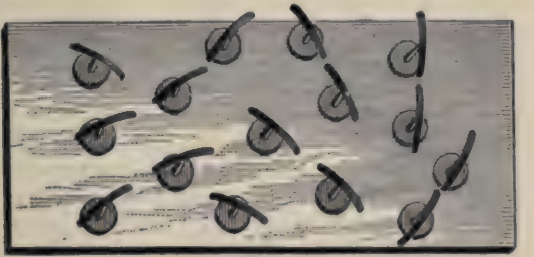


FIG 250

of a strong bar magnet near one end of the board, and at once the magnets begin to turn in parallel directions. Fig. 250 illustrates an

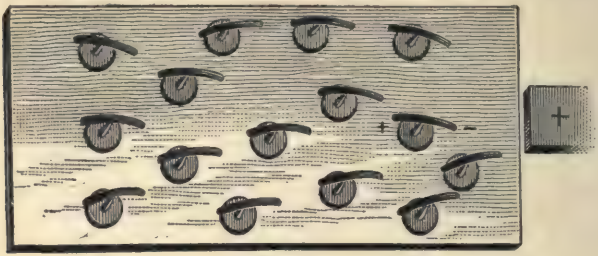


FIG. 251

unmagnetized iron bar, and Fig. 251 the inductive action of a magnet upon such a bar.

PRACTICAL QUESTIONS AND PROBLEMS

1. How do natural magnets become polarized?

2. Suppose a magnetic needle is attracted by a certain body; does this prove that the body is a magnetic substance? Does it prove that the body is polarized? What is the only action that proves polarity?

3. What is meant by a uniform magnetic field? Give an example.

4. Make a drawing of a section of the earth, showing the lines of force. Is the north pole at the surface or below it? What is your proof?

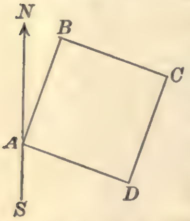


FIG. 252

5. The square piece of land shown in Fig. 252 was surveyed, starting from the point *A*. The line *AB* was found to have the direction N. 20° E. An old survey gave the direction of this line as N. 16° E. Show by a drawing the effect of running this out on the old directions, without allowing for a change in the declination.

6. Why are scissors, knives, and other steel tools often found to be magnetic?

7. What position would a magnetic needle take if suspended, at the earth's surface, over the magnetic north pole? Over the magnetic south pole? At the magnetic equator?

8. Suppose you were to place a magnetic needle upon a thin cork disk on the surface of water in a wooden pail. Would it go toward the north? Why? Make the experiment.

9. What is the effect of iron ore, iron posts, steel wire fences, etc., upon the surveyor's compass?

10. Why are the iron posts of a fence generally found to be magnetized?

LABORATORY WORK

1. Make a bar magnet out of a large knitting needle. Cut two thin disks from a large cork, and put one on each end of the needle, thrusting it through the middle of the disk. Lay a large sheet of glass on a table, and upon it paste a strip of paper, laid off into centimeter divisions. Lay a bar magnet upon two blocks on the glass so that it will be at the same height as the needle, and then place the needle at some scale division as in Fig. 253, and observe results. Repeat the experiment, placing the needle each time 1 cm. farther from the magnet as long as there is any result; and tabulate the results. Make a second set of experiments by reversing the needle. Make the same experiments with a magnetized sewing needle and a horseshoe magnet.

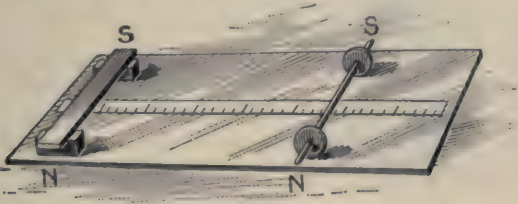


Fig. 253

2. Lay a horseshoe magnet upon a table. Pass a light thread through the eye of a magnetized sewing needle, and by careful manipulation it can be brought to stand horizontally over the ends of the magnet, as in Fig. 254. Explain.

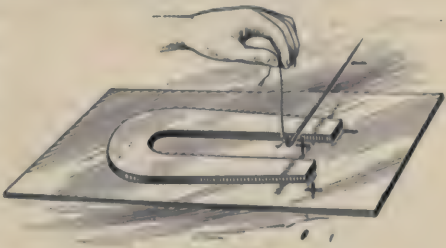


Fig. 254

3. Magnetize a number of sewing needles so that their eyes will be south poles and their points north. Thrust them through very small

corks, leaving the eye half an inch above. Float three of them in a glass of water. Notice their positions, and explain. Now bring the south pole of a bar magnet vertically down over the middle of the glass. Explain the result. Reverse the magnet, and repeat. Explain. Repeat these experiments, using four, five, and six needles. These are called Mayer's floating magnets.

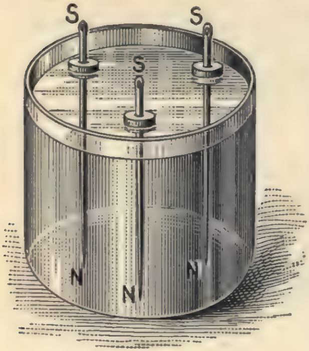


FIG. 255

4. Fill a long, narrow test tube with iron filings. Shake well together and put a stopper in the mouth of the tube to press them down. Rub the test tube, as you would rub a bar of steel with a bar magnet, to magnetize it. Test the tube for polarity, with a magnetic needle. Empty out the filings, and then put them back into the tube again. Test again. Explain.

5. Magnetize a knitting needle. Determine the polarity of each end. File a notch at the middle and break it. Examine for polarity again, and compare with the polarity the needle had before breaking. Break one of these pieces in the middle and examine for polarity. Make a drawing of the broken needle, with the polarity of both ends of each piece marked.

6. Suspend a nail from near one end of a bar magnet, as in Fig. 256. Slide a second magnet over it and observe results. Reverse the second magnet, and again slide it over the first. Explain both results.

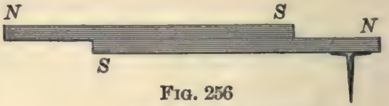


FIG. 256

7. Suspend a horseshoe magnet from the bend and fasten a pail to the armature, or keeper. Pour sand carefully into the pail until the keeper is pulled off. Weigh the pail and contents. Put back the keeper and pail, and pour in *nearly* all of the sand. Keep adding a little sand at intervals of an hour or two — letting the experiment extend over several days if necessary — until the keeper is pulled off, Weigh again. Has the magnet gained in power? Place the keeper and pail on again, and pour in sand until the keeper is pulled off. Weigh again. Has the magnet made a permanent gain in power?

8. Examine, by the method of Experiment 148, the magnetic fields formed by

(*a*) The end of a bar magnet.
(*b*) The side of a horseshoe magnet.
(*c*) The end of a horseshoe magnet.
(*d*) Two horseshoe magnets with like poles opposite.
(*e*) Two horseshoe magnets with unlike poles opposite.
(*f*) Combinations of bar and horseshoe magnets.

These records should be preserved either by the photographic method described in the text, or by taking photographs of the curves by means of a camera placed vertically above them.

9. On one side of a box fix a clamp of the right shape to hold a bar magnet, as in Fig. 257. Lay off a centimeter scale along the side of the magnet from each end. Make a magnetic needle from a piece of watch spring, as in *a*, by splitting a buckshot and pinching it on the magnet at the middle. Suspend this needle in a small glass flask by a silk filament. Set the flask upon the box so that a line from the needle to the magnet will point toward the north. Now remove the magnet and set the needle in vibration by swinging a magnet from east to west near it. Remove all magnets, or iron, from near the needle, and count the number of vibrations per minute. These vibrations are due to the action of the earth's magnetic field alone. Now fasten the magnet to the box, with the south end exactly opposite the needle, and again count the number of vibrations per minute. The increase in the number is due to the field of the magnet alone. Repeat the experiment after moving the magnet up until the first centimeter mark is opposite the end of the needle, and so on at every mark until

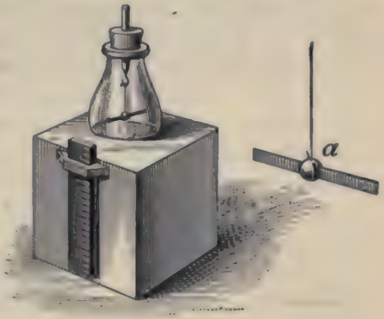


Fig. 257

the middle of the magnet is reached. From the data thus obtained a curve can be made which shall show the distribution of magnetism along a bar magnet. This depends upon the principle that the force which tends to bring the needle back to its position of rest is proportional to the square of the number of vibrations. Construct the curve, as in Fig. 258, by laying off the half length of the magnet vertically, dividing it into centimeter divisions, and from these laying off horizontal distances which are proportional to the square of the number of vibrations at the different points due to the magnet alone. These points, *a*, *b*, *c*, etc., are connected by a line for the curve of distribution of magnetism. Is the pole at the end?

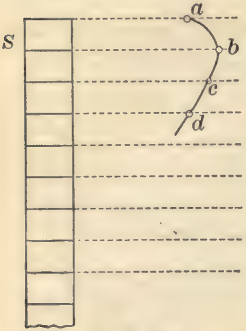


FIG. 258

10. Set a straight pole vertically in the ground, and at night set another in the true north and south line by putting it in line with the first pole and the north star at a time when the north star is directly above or below the middle star in the handle of the Big Dipper. On the following day, set up a magnetic needle on this line and determine the variation. The result will be only approximate.

11. Fasten a circular card, divided into degrees, on one of the supports of the instrument shown in Fig. 242, and determine the dip in your locality.

CHAPTER IX

ELECTRICITY

I. STATIC ELECTRICITY

EXPERIMENT 155. — Hold a warm, dry glass rod over a handful of cork filings, pith balls, bits of paper, etc., and the rod will not affect them. Rub the rod briskly a few times with a piece of silk, and the light bodies will begin at once to fly to the rod, will remain there for an instant, and will then fly back to the table.

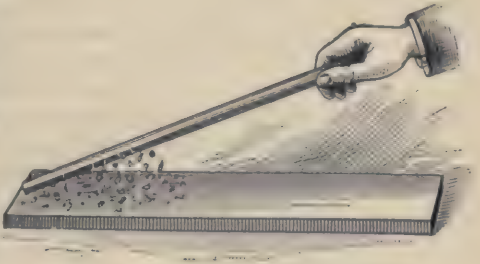


FIG. 259

EXPERIMENT 156. — Place a warm, dry sheet of glass over the bits of paper, supporting it by a book at each end. No effect will be noticed until the glass is rubbed with the silk, when the bits of paper will at once begin to jump to the glass and back again.

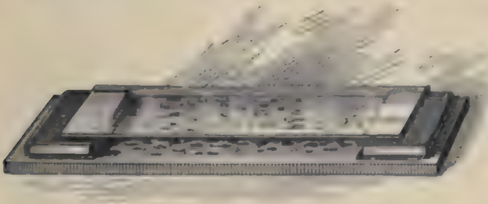


FIG. 260

EXPERIMENT 157. — Repeat Experiment 155, with (1) a stick of sealing wax, (2) a rod of ebonite, and (3) a hard rubber comb, using a flannel pad for a rubber, instead of the silk.

310. The above experiments show that when glass is rubbed with silk, or sealing wax with flannel, there is imparted the property of attracting light bodies. The first record of this property was made by the Greeks about 600 B.C. Because they noticed it in amber (*elektron*) the name *electricity* has been given to the cause of these phenomena, and a body that is capable of attracting others in this way is said to be *electrified*.

EXPERIMENT 158.—Make a wire stirrup as in Fig. 261, and suspend in it a wooden rod two or three feet long. Suspend this by a silk thread from a support and present, near one end, an electrified glass rod. The wooden rod will be at once attracted. Take out the wooden rod, suspend the glass rod, and present the end of the wooden rod; and now the glass rod moves. Suspend both rods, and they move toward each other until they touch.

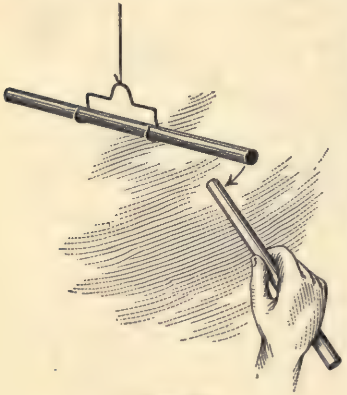


FIG. 261

This experiment shows that the action that takes place between an electrified and an unelectrified body is *mutual*.

311. Two Kinds of Electrification. — We have seen that the glass rod, the sealing wax, and the ebonite rod all attract other bodies when electrified. Their action upon one another may be seen in the following experiment.

EXPERIMENT 159.—Electrify a glass rod and suspend it in the wire stirrup. Bring a wooden rod near it, and it will be attracted. Bring an electrified ebonite rod near it, and it will be attracted more than before. Now electrify a second glass rod and bring it near the end of the suspended rod, and repulsion takes place. Suspend the electrified sealing wax in the stirrup and hold near it a second electrified stick of sealing wax, and repulsion takes place. Hold near it an electrified glass rod and it is attracted. Hold near it an electrified ebonite rod, and it is repelled.

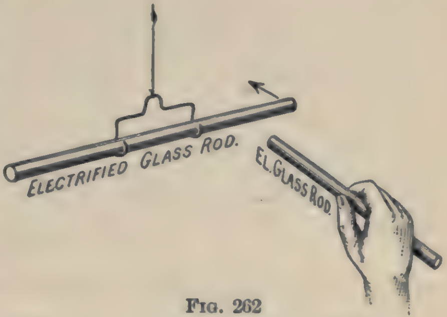


Fig. 262

From this experiment we see that while the electrified glass rod and sealing wax have apparently the same effect upon an unelectrified body, they act differently upon one that is electrified. When this difference was first observed the kind of electrification produced by rubbing a glass rod with silk was called *vitreous*, and that produced by rubbing sealing wax with flannel, *resinous* electricity. These are now called *positive* or + and *negative* or −, respectively. For the sake of convenience these states of electrification will be spoken of as positive and negative electricity.

312. Action of Electrified Bodies upon Each Other. — As a consequence of the action of electrified bodies upon each other, the following laws may be stated:

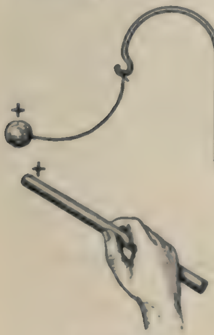


Fig. 263

I. *Bodies charged with like electricities repel each other.*

II. *Bodies charged with unlike electricities attract each other.*

Compare these laws with the laws for magnetic attraction and repulsion.

Experiment 160. — Cut out a number of pith balls with a penknife and roll them in the hands. Use the pith of corn, elder, or, better still, burdock. Suspend one of them from a bent glass rod by a fine silk thread.

Electrify a straight glass rod and bring it near the ball, which will at once be attracted, cling to the rod for an instant, and then fly away charged with a + charge. Rub different bodies, such as dry paper, a rubber comb, dry wood, sulphur, etc., first with silk and then with flannel. How are those charged that repel the ball? If a body attracts a charged pith ball is it a proof that the body is charged?

313. Measure of Electrical Attraction and Repulsion. — The force resulting from the mutual action between two electrified bodies may be expressed by the formula

$$f = \pm \frac{Qq}{d^2}. \qquad (50)$$

In this expression Q and q are the electrical charges of the bodies, and d is the distance between them. By reference to the law of mutual action it will be seen that the + sign means repulsion and the − sign attraction.

314. Electroscopes. — Any instrument by means of which we can determine whether bodies are charged or not is an electroscope. A pith ball arranged as in Experiment 160 is a *pith-ball electroscope.* A common form is the *gold-leaf electroscope*, which consists of a glass jar, through the wooden stopper of which passes a brass rod terminating in a ball on the outside, and having two long, narrow leaves of some thin metal, as gold foil, attached to the inner end. Whenever the ball is touched with a charged body the leaves receive a part of the same charge and diverge in accordance with the first law, as in Fig. 264.

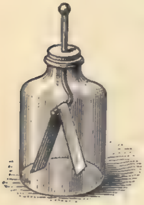


Fig. 264

Experiment 161. — Make a *proof plane* by cementing a thin metal disk to the end of a rubber penholder (Fig. 265). Put this plane in contact with any charged body, and quickly touch the knob of the electroscope with it. Rub a glass rod with silk, touch it with the proof plane, and then bring the

Fig. 265

plane again near the knob of the electroscope. If the leaves diverge still more they show that the first body was charged *positively.* If the leaves fall together somewhat, the probability is that the body is charged negatively; but as the repulsion of the leaves is the only sure test, the proof plane must be charged negatively from sealing wax and again presented to the electroscope. If the leaves now diverge the first body was charged negatively.

315. Conductors and Insulators.—EXPERIMENT 162.—Wind one end of a copper wire a meter long around the knob of an electroscope, and attach a brass ball to the other end. Charge the proof plane from a charged body and touch the ball with it. The leaves of the electroscope will instantly diverge. Replace the wire by a silk thread, and no effect will be seen when the ball is charged. Replace the silk thread by a damp cotton thread, and the leaves will diverge gradually when the ball is charged.

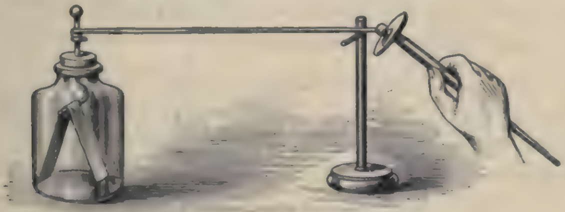


FIG. 266

Bodies like the wire, which carry the charge readily, are called *conductors;* while those like silk, which carry it with difficulty, are called *insulators.* There are no substances that are absolute conductors, neither are there any that are perfect insulators; but the following table gives what are ordinarily classed as conductors and insulators. The substances are arranged in the order of their conductivity.

CONDUCTORS		INSULATORS	
Metals,	Animals,	Dry Wood,	Glass,
Graphite,	Linen,	Dry Air,	Ebonite,
Acids,	Cotton,	Paper,	Shellac.
Salt Water,		Silk,	

The conductivity of bodies depends upon their physical condition, temperature and moisture having a decided effect. Glass becomes a conductor at 200° C. Air under normal pressure is a good insulator, rarefied air is a poor one. Pure water is a very poor conductor, but is rendered a good conductor by the addition of a little salt, or a few drops of acid. Whether bodies are conductors or not also depends upon the character of the electrical charge. A single layer of cotton is insulation between two wires carrying the current for an electric bell, but is no protection whatever against the spark from a charged glass rod. Insulators are also called *nonconductors* or *dielectrics.*

316. Friction develops both Kinds of Electricity. — EXPERIMENT 163. — Rub a glass rod and an ebonite rod together much as a mower whets his scythe. Test each by bringing it near the knob of an electroscope. The glass will be found charged positively, and the ebonite will show an equal negative charge.

317. Can Conductors be electrified by Friction? — If a brass tube is rubbed with either silk or flannel and then tested with an electroscope, no evidence of a charge will be found. This, however, is not a proof that no charge is generated; for any such charge would be carried away by the body of the experimenter as fast as generated, since both the rod and the body are conductors.

EXPERIMENT 164. — Flip a silk handkerchief against the knob of the electroscope, and the leaves will be found to separate. The glass body of the electroscope could not carry away the charge generated by the friction of the silk on the brass ball. Determine whether the charge is positive or negative.

EXPERIMENT 165. — Rub a glass tube an inch or more in diameter with a silk pad. Present the knuckle to a point on the side, and take off a spark. Do this at various points along the tube. Since the glass is a nonconductor you discharge only a small area each time.

If unlike substances are pressed together and then rapidly separated, they will become oppositely charged. This is seen in the fact that sparks can be drawn from a leather belt in running machinery, especially in dry weather.

318. Distribution of Electricity. — If a sphere is placed upon an insulating support, such as a glass rod, and charged with a certain quantity of electricity, a proof plane placed upon any part of its surface will carry away the same charge, as is seen by the equal divergence of the leaves of an electroscope. But if an equal charge is given to an insulated cylinder with rounded ends, the proof plane will carry a much greater charge away from the ends than from any other part of the surface. The comparative *density*, or *quantity of charge per unit area*, is represented by the distance of the dotted line from the surface in Fig. 267. From this it appears that the density is greater at the projecting parts of a body.

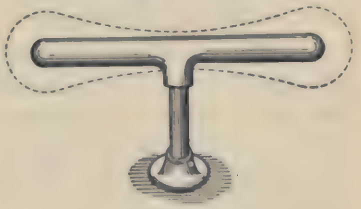


Fig. 267

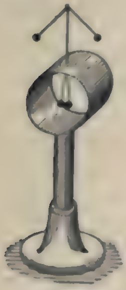


Fig. 268

Experiment 166. — Support a short metal cylinder upon an insulating stand. Fasten a wire 3 in. long vertically into the top of the cylinder. From the top of this wire suspend two pith balls by linen threads. Suspend two others from the inside of the cylinder. Charge the cylinder with the charge from a glass rod; the outer set of balls will fly apart, while the inner ones will remain undisturbed.

From the above experiment we learn that *on an insulated conductor the electrical charge is located on the outside.* A comparison of this result with the law of repulsion will afford an explanation. It follows from this law that, with the same charge, as the outside surface increases the surface density diminishes.

This location of an electric charge on the outside of a conductor holds good only for a condition of rest. If the charge is moving, as when a charged body is discharged, the charge passes through the entire cross section of the body.

319. The Action of Points. — EXPERIMENT 167. — Fix a pin, at its middle, to the end of a stick of sealing wax. Charge an electroscope until the leaves are widely separated. Place the head of the pin against the knob and observe that the leaves gradually fall together. Hold a pin in the hand and bring its point near the knob of a charged electroscope. What happens?

If this experiment (with pin and sealing wax) is made upon a body with a much greater charge than the electroscope, a decided current of air can be felt in front of the point. The density of the charge at the point electrifies the air particles, which, by the law of repulsion, are at once driven off. As each particle takes its own charge away, it is readily seen that a body with pointed surfaces can not be kept charged, however good the insulation.

320. Electrical Potential. — EXPERIMENT 168. — Charge two insulated conductors — tin cans upon glass tumblers will do — with the glass rod, and connect one of them with a gold-leaf electroscope by means of a piece of wire provided with an insulating handle. Notice the extent to which the leaves separate. Remove the wire from the body and discharge the electroscope. Connect the electroscope with the second body and notice the divergence of the leaves. Now connect the two charged bodies together and notice that if the divergence of the leaves of the electroscope was less when connected with the second body than when connected with the first, they will now diverge more widely than before when connected with the second, and *vice versa*. On connecting the electroscope with the first body it will be found to give the same divergence as the second.

From this experiment we conclude that there has been a flow of electricity from the body giving the greater divergence of the gold leaves, to the other. This condition of electrified bodies which sets up an *electric current* in a conductor which connects the two bodies is the *difference of potential* or the P.D. of the bodies.

If the electrified body connected with the electroscope is now connected with the earth, the leaves will at once fall together, showing that the electroscope is discharged. The quantity of electricity in the body is so small that it does not, on being connected with the earth, change the condition of the earth in any perceptible degree. The earth is — for the sake of reference — assumed as the *zero of potential*, bodies positively charged being considered at a higher potential than the earth, while those negatively charged are at a lower potential than the earth. If the difference of potential between two bodies is kept constant, the current passing in the conductor that joins them will be a *continuous current*, while if the P.D. is not constant, the current will be only *momentary*. Potential is analogous to water pressure, and the current to the flow of water that takes place in a pipe connecting two bodies of water at different levels.

321. Capacity. — If two insulated conductors, of the same shape but of different sizes, are charged to the same potential, it will be found that the larger one has a greater charge than the other. This means that there is a difference in their *electrical capacity*. The capacity of a conductor may be expressed by the formula

$$C = \frac{Q}{V}, \tag{51}$$

in which $C =$ capacity, $Q =$ quantity, and $V =$ potential.

The word *capacity* as used in electricity has a meaning different from that usually given to it. We say that the capacity of a quart cup is a quart, meaning *when it is full.* From Formula 51, we see that the capacity of a conductor is the quantity of electricity on it *when its potential is unity.* The quantity that a quart cup can hold is never greater than its capacity — one quart; but the quantity of electricity that can be given to a conductor may be many times its capacity, in which case its potential will be more than unity. Since electricity in its static condition is on the outside of bodies, a wooden ball covered with metal foil has the same capacity as a solid metal ball of the same size.

322. Induction. — Experiment 169. — Bring an electrified glass rod near the knob of an electroscope, and the leaves will begin to diverge when the rod is a foot or more away. Bring it nearer, and the divergence is greater. Remove the rod, and the leaves fall together.

We learn from this experiment that the influence of the charged rod extends to some distance through the air. This action of a charged body upon another body in the *electrical field* which surrounds it, is called *electrostatic induction.*

323. To charge a Body by Induction. — In the above experiment we notice that the electroscope remains charged only so long as the *inducing body* is near it. It is possible, however, to charge the electroscope permanently, as follows:

Experiment 170. — Bring the glass rod near the knob as before, and when the leaves have separated, touch the knob with the finger. The leaves instantly fall together. Now remove first the finger and then the rod, and the leaves again diverge, showing that the electroscope has received a permanent charge.

To explain this action we must recall the first law of the action of electrified bodies upon each other: *like electricities repel each other.* When the electrified rod is brought near the knob, the + of the rod separates the electricities in the knob, wire, and leaves of the electroscope, driving the like kind, +, to the leaves, and holding the unlike kind, −, near to itself in the knob as in Fig. 269. When the knob is touched it is put in contact with the earth, and the + electricity, repelled by the + of the rod, escapes, while the − is held *bound.* Fig. 270 shows this condition. Fig. 271 shows the condition when the contact with the earth is broken and then the glass rod is removed. The − electricity is no longer *bound,* but *free,* and so passes partly from the knob into the wire and leaves, which diverge less than before, but with a charge of − electricity.

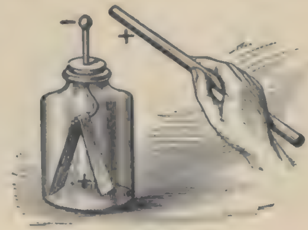


FIG. 269

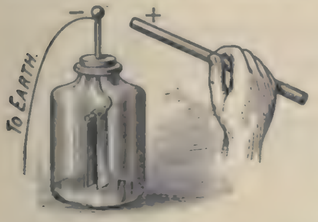


FIG. 270

From this we see that a body can be *charged by induction,* if only some way is provided by which to carry off the electricity that is repelled by the inducing body.

The inductive action of a charged body is well shown in an experiment by Faraday, called the *ice pail experiment.*

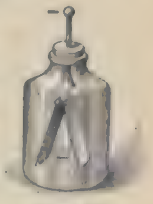


FIG. 271

EXPERIMENT 171. — Place a thin metallic vessel, like a tin can, upon an insulating stand and connect it by a wire with the knob of an electroscope. Suspend a positively charged metal ball by a silk thread and lower it within the can; the leaves at once diverge. Remove the ball, and they fall together. Lower the ball again, and they diverge. Touch the can, and they fall. Remove the finger and then the charged ball, and the leaves separate, charged with negative electricity. Explain.

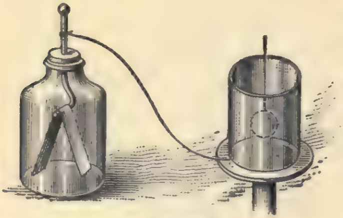


FIG. 272

Discharge the electroscope and again lower the ball. Observe the amount of divergence of the leaves. Let the ball touch the inside of the can. Notice that the divergence of the leaves is not changed. Remove the ball, and the leaves are still separated, charged with positive electricity. Explain.

A thorough study and understanding of the foregoing experiment will give the student a correct idea of the phenomena of induction.

324. Specific Inductive Capacity. — The quantity of electricity that can be given to a body by induction depends upon the extent of its surface, the distance between it and the inducing body, and the character of the *dielectric* that separates them. The property that dielectrics have of transmitting electrical induction is called their *specific inductive capacity.* The specific inductive capacity of air is taken as unity, and that of a few other substances is shown in the following table.

Air . .	1.00	Shellac . .	2.75
Paraffin .	2.00	Ebonite . .	3.40
India Rubber	2.25	Glass . .	6.25

EXPERIMENT 172. — Suspend a charged ball at a fixed distance above the knob of an electroscope and observe the divergence of the leaves. Introduce between the ball and the knob a cake of paraffin, or a plate of glass, first making sure that it is not electrified, and notice the change in the divergence of the leaves.

325. The Electrophorus is a simple and inexpensive instrument for generating an electric charge, and is more convenient than the glass rod and silk pad. A glass plate is fastened upon a board by a wooden frame as in the lower part of Fig. 273. Upon the glass rests a disk of brass or other metal having an insulating handle. To generate the charge the glass plate is rubbed with silk; the brass plate is then placed upon the glass, and the upper surface of the brass is touched with the finger. On lifting the brass plate with the insulating handle it will be found to be charged with a negative charge, which may be taken off as a spark.

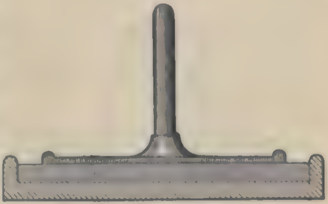


FIG. 273

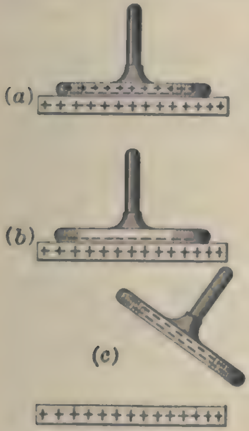


FIG. 274

The action of the electrophorus may be explained as follows. The glass plate becomes charged positively when rubbed with the silk. Since the surface of the glass is uneven, there are but few points of contact when the brass disk is placed upon it, hence the disk becomes charged by induction as shown in (*a*) in Fig. 274.

When the disk is touched the free positive charge escapes, as in (*b*); and when the disk is removed from the glass, the negative charge, which was held bound by the positive of the glass, becomes distributed over the entire surface, as in (*c*).

If a positive charge is desired instead of a negative, the glass plate can be replaced by one of ebonite or wax.

326. Condensers. — The principle of induction is used to give to a body a much greater charge than it would otherwise receive.

Experiment 173. — Cut out a sheet of tinfoil six inches square and place it in the middle of a pane of glass a foot square. Charge the electrophorus and count the number of sparks that you can make pass between the disk and the square of tinfoil. Discharge the tinfoil by touching it. Lift the glass plate from the table and place under it a second sheet of tinfoil, connected with the earth. Replace the sheet of glass. Count the number of sparks that you can now make pass into the upper tinfoil. Put one hand upon the lower tinfoil, and touch the upper tinfoil with the other. How does the *condenser* spark differ from the ordinary?

The simple instrument used in the above experiment contains all that is essential in a condenser, namely, *two conductors separated by a dielectric.* The reason for using a condenser is that we may increase the quantity of electricity without increasing the potential. The quantity of electricity that can be stored on each conductor is directly proportional to its area and inversely proportional to the thickness of the dielectric between the conductors. A convenient form of condenser of large capacity can be made by arranging two sets of sheets of tinfoil as in Fig. 275, and separating them by putting sheets of mica, or paper soaked in melted paraffin, between them.

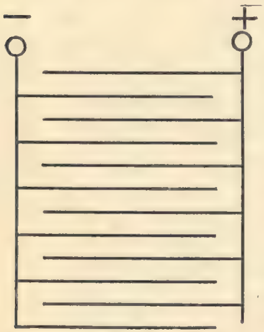


Fig. 275

327. The Leyden Jar is a convenient form of condenser. It consists of a glass jar with a wooden stopper, through which passes a brass rod terminating outside in a metal ball and inside in a chain touching the inner coating of the jar. The jar is coated both inside and outside, to about two thirds its height, with tinfoil pasted on the glass. The jar should be made of thin glass, to give it greater capacity, but it is possible to have the glass too thin, since it is then more easily pierced by a heavy charge.

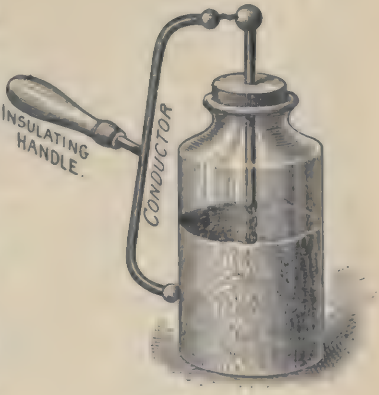


FIG. 276

The Leyden jar is charged by holding it in the hand, or in some other way connecting the outer coating with the earth, and presenting the ball, connected with the inner coating, to the source of electricity. It is discharged by touching the outside coating with one end of a discharger and bringing the other end near the knob of the jar, when the discharge will take place in the form of a heavy spark, as in Fig. 276. The outer coating should be touched by the discharger first, or the heavy spark will tear off the tinfoil coating.

328. Seat of the Charge. — If the discharger is used again a short time after a jar has been discharged, a second and much fainter discharge takes place. This could not be the case if the charge were located in the conducting coatings, as they would be discharged at once.

Experiment 174. — Procure a *Leyden jar with movable coatings,* which consists of a cone-shaped glass jar, (*a*) in Fig. 277, having two tin cones for coatings, one (*b*) fitting the outside and the other (*c*) the inside of the glass. Put the parts together and charge the jar. Remove the inner coating with a glass rod and bring it near an electroscope. It will be found to have no charge. Remove the outer coat and test in the same way. It has no charge. Now put the jar together again, and a spark can be taken from it by connecting the inner and outer coatings.

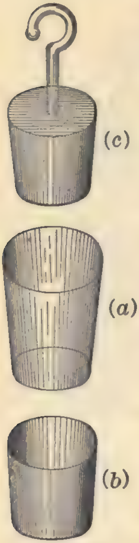


Fig. 277

These results prove that the coatings act simply as a means for collecting the charge, and that its seat is in the glass. As the glass is a poor conductor, the charge does not all pass into the coatings at once, when the jar is discharged. This explains the second spark, which is called the *residual discharge.*

329. Battery of Leyden Jars. — We have learned that the capacity of a condenser is directly proportional to the surface. The method usually employed to secure large capacity with Leyden jars is to connect the outer coatings of a number of jars to the earth or to one terminal of an electrical machine, and the inner coatings to the other terminal. In this way the surface is increased, and a greater quantity of electricity can be stored. The spark from such a battery is much thicker than one of the same length from a single cell.

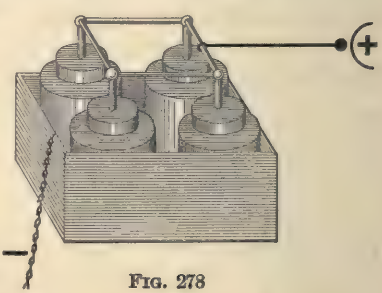


Fig. 278

330. Electrical Machines; Frictional Machines. — The early forms of electrical machines were those in which the charge was developed directly by friction. The most convenient of these was the *plate machine*, which consisted chiefly of a glass disk mounted upon an axis passing through its center. The plate was turned by a handle and the charge was produced by the friction of a pair of rubbing pads at one side of the machine, while it was taken from the plate by a pair of metal combs at the other side. These combs were supported by an insulated brass cylinder, which became charged with positive electricity. To produce any considerable charge, the rubbing pads were connected with the earth by a chain. On account of the friction of the brushes, this machine required a great deal of energy to run it, and partly for this reason it has nearly gone out of use.

331. Induction Machines. — The simplest form of the induction machine is the *electrophorus*. In fact, an induction machine may be considered a *continuous electrophorus*. Many forms of induction machines are in use. The Toepler-Holtz machine is shown in Fig. 279. In this there is a fixed glass disk called the *field plate*, having pasted upon the back side four tinfoil disks, *T*, connected two and two by strips of tinfoil. Over these are pasted sectors of paper. In front of this field plate is a second glass disk, which rotates upon an axis. On the front face of this disk there are pasted, at equal intervals, six tinfoil disks, to the centers of which there are cemented metal buttons. At the points *C* and *C′* on the field plate, brass rods are fastened. These bend over in front of the movable plate and are terminated by small metal brushes, which touch the buttons lightly as they pass along. A rod *AB*, having a metal comb at each end, crosses diagonally in front of the movable plate, while two collecting combs on opposite sides are connected with two brass balls, through which pass two rods. These rods have at their outer ends insulating handles, *K*, and on the inner ends brass balls, or terminals, between which the discharge takes place. A longer and more intensely bright spark may be obtained by attaching a Leyden jar to each terminal. These are shown in place in the figure.

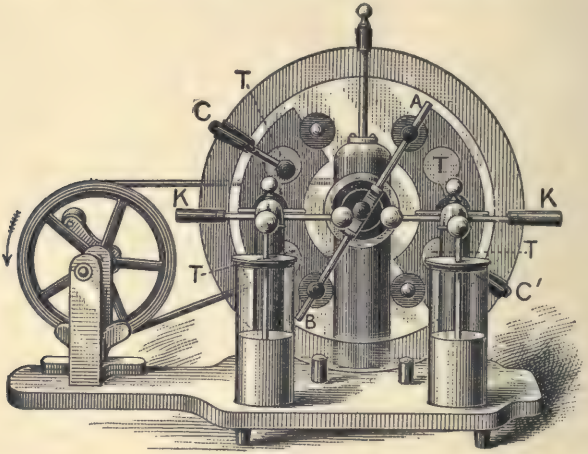


FIG. 279

332. Operation of the Machine. — The machine is first charged by setting the rotating plate in motion and then sending a spark of + electricity from a charged glass rod to one of the tinfoil disks on the back of the stationary plate. This induces a charge on the rotating plate, and when one of the tinfoil disks on this plate comes in contact with a brush on the neutralizing rod *AB*, the + charge passes off and the – charge of the disk is put in connection with that of the paper sector on the other side of the machine by means of the conducting rod *C*. When the disk passes in front of the comb attached to the handle *K*, the − charge is given up to the brass ball which is the negative terminal. The terminals should be put in contact until a hissing sound shows that the machine is charged. When they are separated, a series of sparks will pass from one terminal to the other. On examining the two sides of the machine with a pith-ball electroscope, it will be found that the side that was charged by a spark from the glass rod is positively charged, and the other side is negatively charged. If a spark from a stick of sealing wax is used to charge the machine, it will be found negative on that side and positive on the other. A little study of the sparks that pass between the terminals will show that the polarity of the machine determines the appearance of the spark. The main spark is purple in color, and the ends differ according to their polarity, the negative end being a minute bright point, while the positive end is not so bright; the bright part, however, is longer, being about an eighth of an inch in an inch spark.

333. The Effects of the Discharge. — The main effects of the discharge from a Leyden jar, or electrical machine, may be classed as (*a*) mechanical work, (*b*) heat, and (*c*) light.

334. Mechanical Effects. — EXPERIMENT 175. — Hold a thick piece of cardboard between the terminals of a Holtz machine when it is connected with the condensers, and set the machine in action. A spark will pass, and since the card is a nonconductor, the spark will tear its way through. On examination the hole will be found to have a burr on each side. This indicates that the discharge passed in both directions.

EXPERIMENT 176. — Set a wire upright in a wooden base, and file its upper end to a point. Place over this wire a thin test tube, as in Fig. 280, and bring one terminal of the machine directly over it. Connect the wire with the other terminal, and attach the Leyden jars.

When the machine is put in operation a spark will pass and pierce the tube. If the tube is a thick one, several sparks may go from point to knob over the surface of the glass before it is pierced.

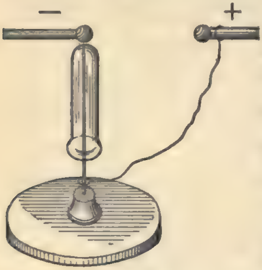


FIG. 280

Any nonconductor, if not too thick, can be pierced by the condenser spark between the terminals of the machine. Cardboard, books, seasoned wood, etc., should be tried. Try a metal plate also. Is it pierced? Why?

335. Heat Effects. — The amount of current that passes when a charged body is discharged through a conductor is but small, and the heating of the conductor is consequently little. When the discharge takes place through a nonconductor, however, the effect is much greater. The spark itself is evidence of this, since in this case enough heat is given off to produce light. The spark from an electric machine is sometimes used to light the gas in buildings where the chandeliers cannot be readily reached.

EXPERIMENT 177. — Bring a gas jet between the terminals of a machine. Turn the handle until the sparks pass, and then turn on the gas. It is lighted at once. Why?

EXPERIMENT 178. — Connect the terminals of the machine with two wires leading to a board, as in Fig. 281. Put shot on the ends of the wires for knobs. Between the knobs put a small pile of gunpowder. Using the condenser discharge, send a spark between the knobs. The effect will probably be mechanical, scattering the powder without igniting it. Introduce a piece of wet string in the circuit, and the spark will ignite the powder.

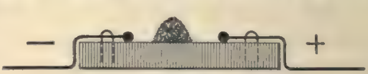


FIG. 281

336. Light Effects. — The light effects of the discharge can best be studied at night, though a room that can be made nearly dark with curtains will do. In the first place, the machine itself affords excellent illustrations of these effects. The shower of purple sparks that follow one another so rapidly that the images of six or eight are continually seen; the sharp spark of the condenser discharge, which makes everything dazzlingly bright, and which takes place so quickly that the rapidly rotating wheel, as seen by its light, seems to stand still; the cascade of minute sparks that flows over the plate near the collecting combs; and the glow of light that tips every point of the combs, — are all light effects of the most interesting kind.

337. The Brush Discharge. — Another very interesting light effect is that known as the *brush discharge.* It is obtained by drawing the terminals two or three inches apart. The distinct sparks will then cease and the discharge will take the form of Fig. 282. Near the positive terminal the discharge is bright like an ordinary spark, but about half an inch away it branches out and becomes a purple glow until the negative pole is reached, where there are a number of minute bright points.

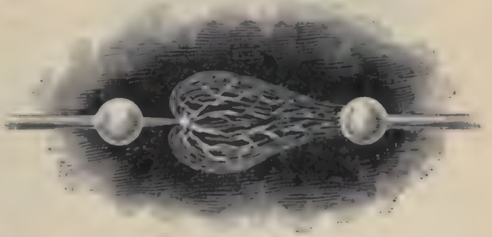


FIG. 282

EXPERIMENT 179. — Cover one side of a dry white pine board with a heavy coat of shellac. Next place on this a layer of thin tinfoil and cover this with shellac, rubbing it down fast to the board. Dry thoroughly and then with a sharp knife cut the tinfoil into squares a quarter of an inch on a side. Connect the tinfoil at the ends of the board with the terminals of the machine, and on sending the spark it will be seen to pass the entire length of the tinfoil, causing a spark at every place where the conductor has been cut.

Boards like the one described can be made in any desired shape, and afford excellent illustrations of the fact that if a discharge takes place along a broken conductor a spark will occur at every gap.

Experiment 180. — Take a piece of No. 30 magnet wire and with a knife, or pair of cutting pliers, cut the wire every half inch without cutting the insulation. Suspend this from the ends over the terminals of the machine, and when the machine is put in motion every break in the wire will furnish a bright spark. The insulation covering the pieces of wire will hold them in place, and they can be made into many fanciful shapes.

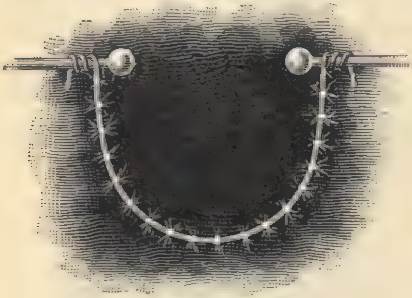


Fig. 283

338. The Discharge in Rarefied Gases. — The electric discharge that takes place in the air at ordinary pressure gives rise to a bright light and a sharp report. If the discharge takes place in a partial vacuum, however, the light is very much softened and the discharge is a silent one. Glass tubes which have terminals sealed in the glass, and from which the air is partly exhausted, have been made for the study of these phenomena, but as they are used mainly with the induction coil the consideration of them will be deferred until that subject is taken up. The following experiment, however, illustrates the general action of such tubes: —

Experiment 181. — Hold the bulb of an incandescent lamp between the terminals of a Holtz machine in a darkened room, and set the machine in motion. The lamp will be filled with a pale glow which will come and go in flashes as long as the machine is turned.

339. The Discharge of the Leyden Jar Oscillatory. — From Experiment 175 the conclusion was drawn that the condenser discharge is in both directions. Other experiments verify this conclusion and show that the discharge is an oscillation, the charge going first in one direction and then in the other. This is analogous to what would take place in a U-tube, such as is shown in Fig. 284, if it were filled with water in the two arms to the points *A* and *B*. If now the clamp at *C* is suddenly opened, the water will flow from the left side to the right, and instead of stopping at the level line *xy*, will pass on to *D* and *E*. The same thing now takes place in the opposite direction, and so continues alternating until the water finally comes to rest on the line *xy*.

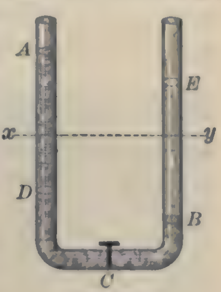


FIG. 284

340. Atmospheric Electricity. — No one who has observed both the condenser discharge from a Holtz machine and lightning, has failed to notice the similarity between them. The identity of lightning with the discharge of frictional electricity was proved by Franklin in 1752. In Figs. 285 and 286 photographs of both are compared.

341. The Cause of the Clouds being Charged. — Experiment has proved that in some conditions of the atmosphere the vaporization of water sends away the molecules of water vapor charged with a positive charge. As these molecules join and form clouds the potential rises. Suppose, for example, that one thousand molecules unite to form a drop. The volume of the resulting drop becomes one thousand times the volume of the molecule, but its surface is much less than one thousand times the surface of a molecule, and as the charge of electricity is on the surface the potential is very much raised.

This high potential positive charge on the clouds induces a negative charge in the earth beneath it, and as soon as the difference of potential between them becomes great enough the spark, or lightning flash, breaks through the air, taking the path of least resistance, and generally striking a tree or some other high object. It happens in some conditions of the atmosphere that the negative charge is induced in a neighboring cloud, and then we see a beautiful display of lightning between the two oppositely charged clouds, and no damage is done by the discharge.

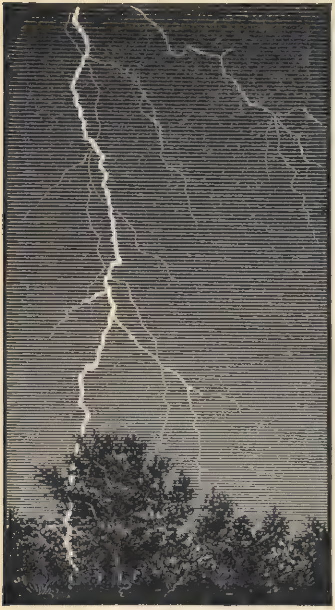


Fig. 285

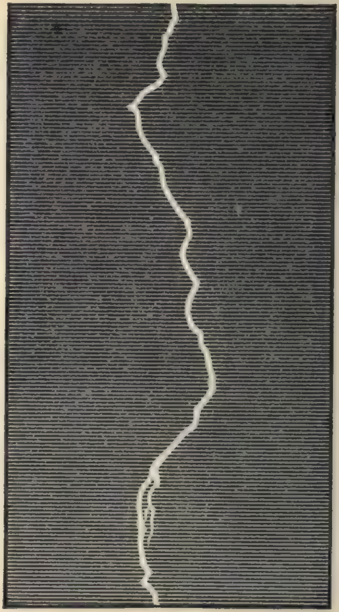


Fig. 286

342. Thunder. — In the case of a lightning flash the air is the dielectric which is broken through, and since the velocity of the discharge is very great it leaves a long, irregular hole in the air that it has passed through. As every square inch of the surface of this hole is pressed inward with a pressure of 15 lb. the walls come together with a terrific crash. To a person who is near the flash the sound is that of a crash, but to one at some distance the direct report is mingled with its echo from the clouds and the earth, producing the deep, rolling sound that we call *thunder*.

343. Lightning Rods. — Since lightning tends to take the path of least resistance, metal rods are sometimes placed upon buildings to protect them. These rods should be continuous, should terminate above in a number of bright points, and should terminate below in copper sheets buried in earth that is always moist. We have already seen that the effect of points is to discharge a charged body quietly. It is probable that the most effective work done by lightning rods is in discharging the clouds quietly, and thus preventing the lightning stroke, instead of merely acting as a conductor when it comes.

344. Sheet Lightning. — During the hot weather of summer there are very few nights in which one cannot observe the reflection, from clouds near the horizon or from the air itself, of flashes of lightning in a distant storm. The storm itself may be fifty miles or more away and entirely below the horizon. This form is often erroneously called *heat lightning*.

345. The Aurora. — The Aurora Borealis or Northern Lights is the name given to beautiful light phenomena that are seen in the northern part of the northern hemisphere. The general explanation given is that the aurora is an electrical discharge taking place in the upper regions of the air, where its density is much less than at the surface of the earth. The position of the aurora and the direction of its streamers seem to be definitely connected with the magnetic condition of the earth; the streamers centering at the north magnetic pole as stated in § 305, note.

PRACTICAL QUESTIONS AND PROBLEMS

1. How would you determine the kind of electricity with which a body is charged?

2. How would you prove that the rubbing of two bodies together develops both kinds of electricity?

3. How would you electrify a brass rod by friction?

4. Why does the electric charge pass to the outside of a hollow conductor?

5. Make drawings to show the electrical condition of an insulated conductor (*a*) when a charged conductor is brought near it; (*b*) when the conductor is touched with the finger; (*c*) when the charged conductor is removed.

6. What would be the effect of running a metal pin, connected with the earth, through the glass plate of an electrophorus, until it almost or quite touches the disk when it is resting on the glass? Explain.

7. Suppose four bodies, *A*, *B*, *C*, and *D*, to be placed as in Fig. 287; *A* to have a charge $q = +18$, *B* to have a charge $q' = -12$, etc. Find the expression for the action that will take place between these bodies along the lines given in the figure.

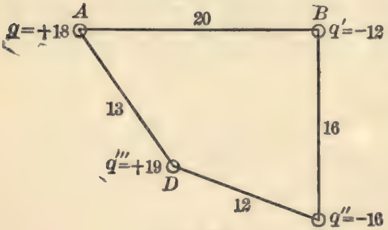


FIG. 287

8. Describe the physiological effect of the discharge from a Leyden jar.

9. A pith ball is placed upon a metal plate connected with the earth. A similar plate connected with the positive pole of an electric machine is suspended over it. The pith ball rapidly passes from one plate to the other. Explain.

10. Why can you not charge a Leyden jar heavily if you set it on a glass plate?

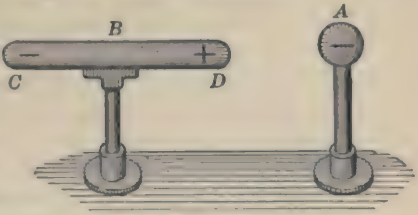


FIG. 288

11. Suppose a flash of lightning is seen at a distance of 4 mi. How long before the thunder will be heard, if the temperature is 70° F.?

12. Suppose two conductors are as shown in Fig. 288. Touch *B* at *C*; what happens? Touch *B* at *D*; what happens? Why can you not remove the + from *B* by touching it?

LABORATORY WORK

1. Suspend by silk thread, from an insulated support, a metal ball such as is used on the end of a curtain pole. Make four pith balls from the pith of a burdock, and suspend them by silk threads from the same support, so that they will rest against the metal ball. Charge the ball with a glass rod and explain the result.

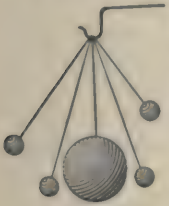


FIG. 289

2. Cut out a piece of sheet lead the size of a nickel. Drive a sharp pin through the middle. Cut a wheat or rye straw a foot or more long and stick a pith ball on each end. Glue a joint cut from another straw to the middle of this for a cap, and balance it on the pin point. You have now an electroscope that will serve for a great many experiments. Place it upon a piece of dry glass and it becomes insulated (Fig. 290).

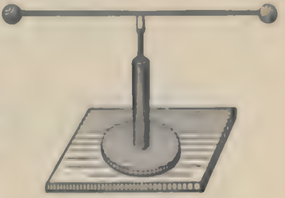


FIG. 290

3. Charge the straw electroscope with a + charge from a glass rod rubbed with silk. Take rods of glass, rubber, shellac, sealing wax, etc., and rubbers of silk, cotton, linen, flannel, catskin, etc., and determine the kinds of charge produced by rubbing each rod with the various rubbers. Arrange the materials used in the form of a scale such that every substance shall have a + charge if rubbed

with one below it in the scale and a – charge if rubbed with one above it.

4. Prove with your electroscope that both kinds of electrification are produced when you rub two of the rods together.

5. Get three glass balls such as are used for Christmas decoration, and cover them with thin tinfoil or paint them with bronze or metallic paint. Suspend one by a small wire, one by a linen thread, and one by a silk thread. Holding the end of the thread in your hand, charge each ball from the machine, and by bringing the balls in turn near your electroscope test the relative conductivities of the wire, linen, and silk. Test the silk also after wetting it.

6. Make an insulated stool by resting a board on four heavy tumblers. Let some member of the class stand upon it and take hold of one terminal of the machine. Let any one standing on the floor present the knuckle to some part of the one on the insulated stool. Explain what takes place.

7. Suspend a bell from each terminal of a Holtz machine by a small chain. Between them suspend a metal ball by a silk thread. Remove the condensers from the machine, turn the handle of the machine slowly, and explain what takes place.

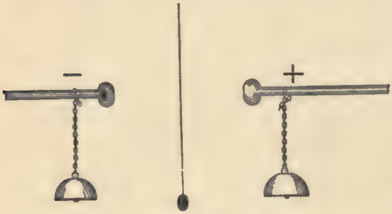


FIG. 291

8. Fill a bottle with smoke and lead into it the sharp end of a rubber-covered wire, the other end of which is connected to one terminal of a Holtz machine. Set the machine in motion and explain the results.

9. On each side of a plate of glass 1 ft. square paste a piece of tinfoil 9 in. square. Hold the plate so that one of the tinfoil surfaces will rest upon the palm of the hand. Let a wire from one side of the machine rest upon the upper tinfoil. Turn the machine a few times and remove the wire. Drop a penny upon the upper foil and then take it off with the free hand.

10. Smoke both sides of a pane of glass by holding it over burning birch bark or camphor. Place this between the terminals of the Holtz machine and send a condenser spark over the plate. Study carefully the path traced.

11. On one side of a sheet of glass cement (preferably with shellac) a series of parallel tinfoil strips connected at alternate ends as in Fig. 292. When the strips are thoroughly dry cut them through with a sharp knife, forming a figure of any shape you wish. Take it into a dark room and send a spark through the strip by connecting the terminals *A* and *B* with the two sides of the machine. The current will pass through the foil, giving a bright spark wherever the circuit is broken by a knife cut, and showing the outline of the desired figure.

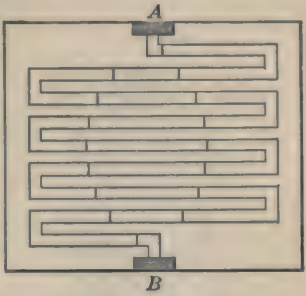


FIG. 292

12. Take a photograph of the condenser discharge of the machine, as follows. Set the machine in operation at night and when you have a spark four or five inches long focus it with the camera. Put on the cap, put in the plate, draw the slide, and uncap the camera just after a discharge. Immediately after the next discharge cap the camera and then develop the plate with a developer which will give plenty of density. A study of the print made from the negative will be very interesting. Fig. 286 shows the photograph of such a discharge.

II. CURRENT ELECTRICITY

346. The discharge of electricity that takes place when a spark passes between the coatings of a Leyden jar is an electric current. The time during which the current passes, however, is very short, hence such a current is discontinuous.

Continuous currents are produced whenever a conductor connects two points at which a difference of potential is constantly maintained.

EXPERIMENT 182. — Make a solution of sulphuric acid by pouring slowly 10 c.c. of the acid into 100 c.c. of water. Place a strip of copper and a strip of zinc in the jar containing the dilute acid. As long as the plates are separated, the only action that takes place is the formation of a few hydrogen bubbles on the surface of the zinc plate.

As soon, however, as the two plates are brought in contact — which may be done by bending the plates as in Fig. 293 — there is a rapid giving off of hydrogen from the surface of the copper plate.

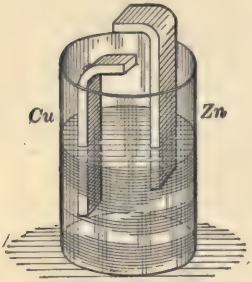


FIG. 293

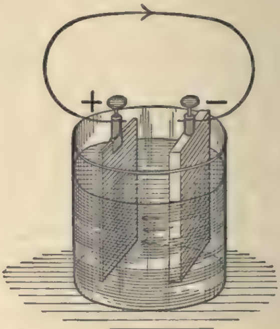


FIG. 294

EXPERIMENT 183. — Solder a copper wire to a thin sheet of copper, and attach a binding post to a zinc battery plate. Repeat Experiment 182 with these plates and observe that the change in the formation of gas takes place just when the copper wire is attached to the binding post on the zinc plate. Bring the connecting wire over and parallel to a magnetic needle, and the needle will be deflected as soon as the wire is touched to the binding post.

347. The Electric Current. — In the above experiment the wire acquires a new property. The cause of this new property is the passage of an *electric current* when the wire is joined to the zinc. The setting up of the current in this case is due to the fact that the acid dissolves the zinc more rapidly than it does the copper and thus sets up a difference of potential between the plates, the zinc being charged negatively with respect to the copper, and the copper positively with respect to the zinc. As soon as the plates are joined by a wire, as in Fig. 294, the current passes in the external circuit from the copper to the zinc, while the difference of potential is maintained by continued chemical action in the cell.

348. The Poles of a Battery. — The apparatus just described constitutes a voltaic cell, or galvanic battery. The terminals of the plates to which the conductor is attached are called the *poles* of the cell, the zinc being the negative and the copper the positive pole. When the poles are joined by a conductor, the cell is on a closed circuit; when they are not, it is on an open circuit.

349. Chemical Action in the Cell. — The phenomena taking place in the cell are practically as follows: When the zinc goes into solution with the H_2SO_4 it does so in the form of *ions*, *i.e.* atoms or groups of atoms, charged with positive electricity. These zinc ions leave the zinc plate negatively charged by the separation, and displace the positive hydrogen ions of the solution of H_2SO_4, forming $ZnSO_4$. The ions of displaced hydrogen move toward the copper plate, and, discharging their positive electricity upon it, pass off in the form of hydrogen gas. In chemical symbols the action is as follows:

$$Zn + H_2SO_4 = ZnSO_4 + H_2.$$

If the cell is on an open circuit, this action diminishes as the quantity of $ZnSO_4$ increases, and finally stops, having produced a difference of potential between the zinc and copper plates that constitutes the electromotive force of the cell. If the cell is on a closed circuit, the positive charge on the copper plate discharges through the circuit and neutralizes the negative charge on the zinc plate, producing an electric current, and the action is continuous. The migration, as it is called, of the H ions toward the copper, and of the SO_4 ions toward the zinc, is dependent upon the dissociation of the H_2SO_4 into hydrogen, $\overset{+}{H}\overset{+}{H}$, and sulphion, $\overset{-}{SO_4}$, in the solution.

350. Local Action; Amalgamating the Zinc. — When the strip of zinc was placed in the acid in Experiment 182, hydrogen bubbles were given off from its surface. This is due to what is called *local action*, which is caused by impurities in the zinc, such as carbon or iron.

The existence of these impurities can be proved by leaving the zinc in the acid for five minutes, when it will be found covered with a black deposit that can be wiped off. If a particle of carbon is at *A* (Fig. 295), a local current will be set up between it and the zinc, and as a result hydrogen will be set free. In order to prevent this action, which reduces the surface of the plate for the main current, the zinc is cleaned by dipping it in dilute sulphuric acid and then rubbing with mercury. This has the property of dissolving the zinc and forming a covering over the particles of carbon, as in Fig. 296, thus preventing local action.

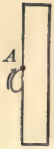


Fig. 295

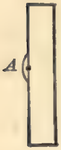


Fig. 296

351. Polarization of the Cell. — When the circuit is made in the simple voltaic cell it is noticed that, while bubbles of hydrogen rise to the surface of the liquid, the copper plate is kept pretty nearly covered by them all the time. This has two effects: (1) to reduce the amount of surface of the plate exposed to the liquid, and (2) to reduce the difference of potential between the plates. Both of these results tend to lessen the amount of current that can be sent by the cell. The usual way in which this difficulty is overcome is to use a kind of liquid that will oxidize the hydrogen before it is deposited on the plate.

352. Different Forms of Cells. — There are many different forms of cells in use, and but few will be described. The cells generally used have zinc as the metal to be acted upon, and may be grouped in classes, of which the following are types.

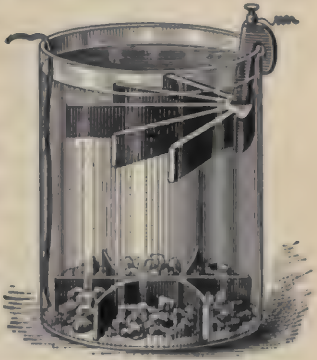


FIG. 297

353. The Gravity Cell — of the crowfoot type — is shown in Fig. 297. A star-shaped group of copper sheets, surrounded by crystals of copper sulphate, is placed in the bottom of a glass jar. Water, to which a few drops of sulphuric acid have been added, is poured in until the cell is nearly full, and then a zinc plate or "crowfoot" is hung from the upper edge of the jar. The Daniell cell, an early form, had the zinc in a porous cup containing dilute sulphuric acid, while the copper and copper sulphate were in the larger glass jar in which the porous cup was placed. As the sulphuric acid acts upon the zinc, zinc sulphate is formed, and since this is lighter than copper sulphate, they keep separate in the gravity cell without the porous cup. Since polarization does not take place in this cell, it maintains a practically constant difference of potential at its terminals, and is capable of giving a constant current. This is the cell ordinarily used for telegraphic work. With zinc sulphate the reaction may be expressed as follows:

Before action: $(a)\ \mathrm{Zn} + (b)\ \mathrm{ZnSO_4} \parallel (c)\ \mathrm{CuSO_4} + (d)\ \mathrm{Cu}$.

After action:

$$(a-1)\,\mathrm{Zn} + (b+1)\,\mathrm{ZnSO_4} \parallel (c-1)\,\mathrm{CuSO_4} + (d+1)\,\mathrm{Cu}.$$

In these expressions the parallel lines represent the line of separation between the zinc sulphate and the copper sulphate. The action may be described as follows: The zinc goes into solution because the force tending to bring the Zn ions into solution is greater than that tending to bring the Cu ions into solution. The stronger the $ZnSO_4$ solution, the more will it react by osmotic pressure against the solution tension that forces the Zn ions into solution, and the stronger the $CuSO_4$ solution, the greater will be the osmotic pressure that causes the copper ions to be precipitated upon the Cu plate.

When this cell is in good condition the blue solution of copper sulphate should fill the jar to a little above the middle, and the line of separation between it and the zinc sulphate solution should be clearly defined. If the cell is unused for some time the copper solution will reach the zinc and copper will be deposited upon it. The cell can be brought back to its proper condition by short-circuiting it, that is, connecting the two terminals by a short piece of wire for a few hours.

As the water evaporates, the zinc sulphate crystallizes in the form of white crystals around the edge of the jar, and unless this is coated with paraffin, the crystals will form over the top and down the outside of the jar.

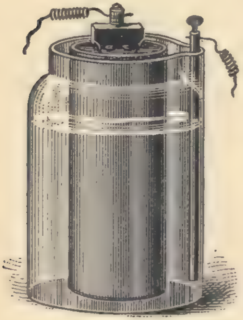


FIG. 298

354. The Leclanché Cell (Fig. 298) consists of a glass cell within which is placed a porous cup containing a bar of carbon, around which is packed a mixture of manganese dioxide and coke. The top of the porous cup is sealed to keep the contents in place. The carbon is the positive pole and a rod of zinc placed in the glass jar outside the porous cup is the negative. The liquid used is a solution of ammonium chloride (sal ammoniac). This cell polarizes rapidly and is suitable for open circuit work only. It is largely used for electric bells and needs but little attention after it is once properly charged.

355. The Bichromate Cell. — In this form of cell the chemical action upon the zinc goes on vigorously whether the circuit is open or closed, and for this reason the zinc is so arranged that it can be raised out of the liquid when the current is not needed. A common form is that known as the bottle form, shown in Fig. 299. Two plates of carbon are suspended from the top of the bottle, while between them is a rod carrying at its lower end a zinc plate that can be raised and lowered at will. Plunge batteries are frequently made of a number of rectangular glass jars, with the carbons and zincs so arranged that they can both be raised from the liquid when not in use.

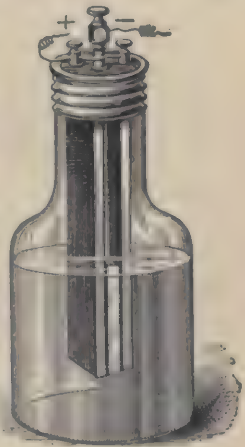


FIG. 299

The solution used may be either potassium bichromate or chromic acid, but the latter is the most convenient to make. The following formulas are simple and give satisfactory solutions.

Potassium Bichromate Solution. — Dissolve 1 lb. of potassium bichromate in 12 lb. of hot water. Add slowly, while stirring with a glass rod, 2 lb. of commercial sulphuric acid. Cool for 24 hr. before using.

Chromic Acid Solution. — Dissolve 160 g. of chromic acid in 1420 c.c. of water and add slowly, stirring all the while, 90 c.c. of sulphuric acid.

356. Electro-motive Force, Resistance, Current. — The difference of potential at the terminals of a cell when it is on open circuit is its *electromotive force*, or E.M.F. It is equal to the sum of all the differences of potential that exist when a cell is sending a current. If we suppose a cell to be sending a current through the circuit from A to B, C, D, and back to A (Fig. 300), the sum of the differences of potential between A and B, B and C, C and D, and D and A is equal to the E.M.F. of the cell. The *practical unit* of E.M.F., and also of potential difference, is the *volt*.

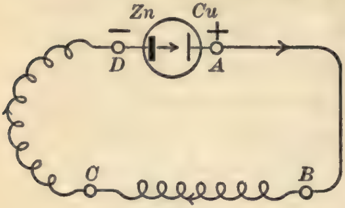


FIG. 300

When the two poles of a cell are connected by a conductor, as in Fig. 300, a current is said to flow from the + to the −. The *practical unit* of current is the *ampere*.

If we connect the poles of the cell by a short, heavy wire, and measure the current that passes, and if we then connect the poles with a long, thin wire, and again measure the current, we find that the greater current is passing in the first case. Since we are using the same cell, the E.M.F. is unchanged, hence we can see that the wire has a certain property that determines the amount of current. This property is called *resistance*, the unit of which is the *ohm*. The current of electricity passing along a wire is somewhat analogous to the flow of water in a pipe. The current or amount of water that flows through a pipe depends upon two things: (1) the difference between the water levels at the ends of the pipe, or the "head" of water; and (2) the size and smoothness of the inside of the pipe. The "head" or *difference of water pressure* at the two ends of the water pipe may be compared to the *difference of potential*, or difference of electrical pressure, at the ends of a wire; the *resistance* to the flow of water in the pipe, depending on size and roughness, may be compared to the *resistance* to the electrical current depending on the cross section and material of a wire; and the resulting *current* of water may be compared to the electrical *current*.

357. Ohm's Law, formulated as the result of experiment, is of very great importance. It is to the effect that the relation between the *electro-motive force*, *resistance*, and *current*, may be expressed by the formula

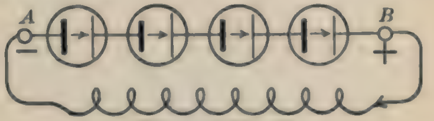
$$C = \frac{E}{R}. \tag{52}$$

This may be written

$$\text{Amperes} = \frac{\text{Volts}}{\text{Ohms}}, \text{ or } A = \frac{V}{O}.$$

From this law we can find the current that a known E.M.F. will send through a certain resistance, the resistance through which a known E.M.F. will send a given current, or the E.M.F. required to send a certain current through a known resistance. The law may also be applied to difference of potential instead of to E.M.F.

358. Arrangement of Cells in a Battery; Series Grouping. — When two or more cells are coupled in series the copper of one is joined to the zinc of the next, while the outside copper and zinc form the terminals of the battery, as A and B in Fig. 301. For this grouping the E.M.F. of one cell is added to that of the next, and the total resistance is the



External Circuit

FIG. 301

sum of the resistances of all the cells; hence Ohm's Law will be written

$$C = \frac{SE}{Sb + R}, \tag{53}$$

in which S is the number of cells in series; b, the internal resistance of each cell; and R, the resistances of all conductors and instruments through which the current passes.

Example. Suppose 4 cells to be coupled in series, the E.M.F. of each to be 1.02 volts, and the internal resistance of each 2.4 ohms, what current will they send through an external resistance of 27 ohms?

$$C = \frac{SE}{Sb + R} = \frac{4 \times 1.02}{4 \times 2.4 + 27} = \frac{4.08}{36.6} = .111 \text{ ampere.}$$

359. Parallel Grouping. — In the *parallel* or *multiple* method of grouping, the coppers are all joined to one terminal and the zincs to another. This gives the same result as if all the plates were in one large cell. The E.M.F. is the same as it would be for a single cell, while the internal resistance is less. Ohm's Law will be

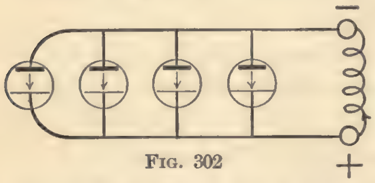


Fig. 302

$$C = \frac{E}{\frac{b}{P} + R}, \tag{54}$$

in which P is the number of cells in parallel.

Example. — Suppose the same four cells as in § 358 to be grouped in parallel and to be coupled to the same resistance. What will be the current?

$$C = \frac{E}{\frac{b}{P} + R} = \frac{1.02}{\frac{2.4}{4} + 27} = \frac{1.02}{27.6} = .037 \text{ ampere.}$$

360. The Series and Parallel Grouping is a combination of the two methods given above. In Fig. 303, there are 6 cells arranged 2 in series and 3 in parallel. In Fig. 304 the same 6 cells are coupled 3 in series and 2 in parallel. In every case $N = SP$, in which N is the total number of cells, S the number in series, and P the number in parallel. Ohm's Law applied to this coupling is

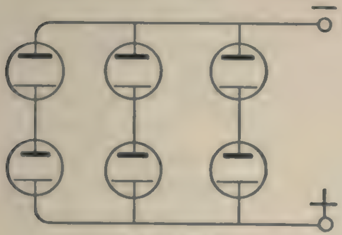


Fig. 303.

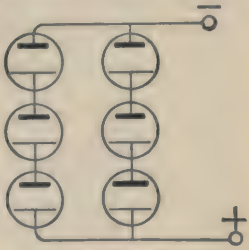


Fig. 304

$$C = \frac{SE}{\frac{Sb}{P} + R}. \qquad (55)$$

Example. — If the cells in Fig. 304 are the same as those used above, with the same external resistance, then

$$C = \frac{SE}{\frac{Sb}{P} + R} = \frac{3 \times 1.02}{\frac{3 \times 2.4}{2} + 27} = \frac{3.06}{30.6} = .10 \text{ ampere.}$$

The formulas given above for these different groupings are important, and are applicable to any form of continuous current generators, dynamos as well as cells.

361. Arrangement of Cells for Maximum Current. — In order to get the maximum current from a battery the cells should be grouped in such a way that their internal resistance will be as near as possible the external resistance of the circuit. This means that if R is large the cells should be grouped in series; if it is small, they should be in parallel; and if it is neither very large nor very small, such a grouping should be made as will make $\frac{Sb}{P} = R$, if possible.

362. Maximum Efficiency. — The arrangement for maximum current is not the one for maximum efficiency, since, as the internal resistance is equal to the external, just half the work of the current is spent in heating the cells. The efficiency will increase if the internal resistance is made small compared with the external, for now the greater part of the work will be employed outside the cell. With maximum current the efficiency is just 50 per cent.

PRACTICAL QUESTIONS AND PROBLEMS

1. Two cells each having an E.M.F. of 1.02 volts and an internal resistance of 1.9 ohms are put in circuit with a bell and push button (Fig. 305), the resistance of which, with the line wire, is 7.3 ohms. Find the current when the button is pushed.

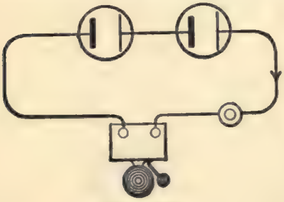


FIG. 305

2. Draw a figure showing these cells coupled in parallel. What current will they give to the same bell circuit?

3. Three cells, each having an E.M.F. of 1.9 volts and an internal resistance of 1.3 ohms, are coupled in series with an external resistance of 12.8 ohms. What current will they give?

4. What current will they give if coupled in parallel?

5. Suppose the external resistance is .4 ohm instead of 12.8 ohms. Find the current the same cells will give, (*a*) when coupled in series, (*b*) when coupled in parallel.

6. Sixteen cells, each having an E.M.F. of 1.8 volts and an internal resistance of 1.7 ohms, are coupled to an external resistance of 2.1 ohms. Draw a figure of the cells coupled so as to give maximum current.

7. Draw a figure of the coupling that will give maximum current with the same cells if the external resistance is 6.8 ohms.

LABORATORY WORK

1. Couple a voltmeter to the terminals of every cell in the laboratory and make a record of the reading in each case. This reading

is the potential difference at the terminals of the voltmeter, and not the E.M.F. of the cells, though the two differ very little.

2. Couple any two cells of the same kind in series and read with the voltmeter. Does the reading substantiate the statement of § 358? Couple all that you have of the same kind in series and read.

3. Couple the same cells in parallel and read their voltage. Is the voltage changed by coupling in parallel?

4. Couple a cell, an ammeter, and a resistance box in series as shown in Fig. 306. Put in a resistance of 1 ohm and read the current. Change the resistance to 2, 3, and 4 ohms successively and read the current for each. Does the current decrease as the resistance increases? Is this in accordance with Ohm's Law?

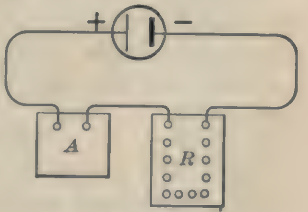


FIG. 306

5. Using six gravity cells, find what method of coupling gives the maximum current, (*a*) when the external resistance is ½ ohm; (*b*) when it is 5 ohms; (*c*) when it is 20 ohms. Try a number of different groupings for each case and see whether the results are in accordance with Formulas 53, 54, and 55.

III. THE EFFECTS OF THE CURRENT

363. Heating Effects. — EXPERIMENT 184. — Connect two cells of a plunge battery in series with a short piece of German silver wire No. 30. Plunge the zincs, and the wire will become red-hot unless you have too long a piece. Use the same length of No. 30 copper wire and repeat. Can you explain the reason for any difference in the action? Repeat, using a heavy current.

FIG. 307

EXPERIMENT 185. — Bore a shallow hole in the middle of one face of a square block. Fit the block with two binding posts and connect them by a wire made of two pieces of copper wire No. 18, joined by a half-inch of German silver wire No. 30, which crosses the hole on the block. Couple three or four cells of a plunge battery with this block by wires 10 ft. long, pile gunpowder loosely over the German silver wire, and plunge the zincs.

This experiment illustrates one of the methods used to fire mines from a distance.

364. The Laws of Electric Heating. — The heat developed by a current in a circuit is proportional: (*a*) to the square of the current, (*b*) to the resistance of the circuit, (*c*) to the time during which the current passes. This is usually expressed by the formula

$$H = C^2Rt.$$

In order to express this in heat units, there must be introduced a factor which shows the relation between this product and the ordinary heat units. Hence we may write

$$H = .24\ C^2Rt, \qquad (56)$$

in which the current is expressed in amperes, the resistance in ohms, and the time in seconds. The result, H, is in *calories*.

This heating effect is a waste in many uses of the current, and is called the *heat loss*. It is made use of in *electric heating*.

365. Chemical Effects. — EXPERIMENT 186. — Fit two corks to the two sides of a U-tube. Through these corks pass copper wires, with platinum terminals. Fill the tube nearly to the top of the terminals with a solution of sodium sulphate, colored with blue litmus. Couple two or three cells to the copper wires, and in a few minutes the solution near the + terminal will turn red, showing the presence of an acid, while the color at the − terminal shows the presence of an alkali.

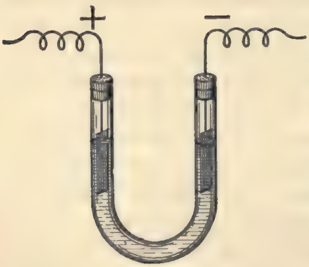


FIG. 308

EXPERIMENT 187. — Rinse the U-tube used in the above experiment, and fill it nearly full of water, to which a few drops of sulphuric acid have been added. Cut a notch along the side of each cork and couple three cells of a plunge battery. Bubbles of gas will be noticed at each terminal. Those given off at the + terminal are oxygen and those at the – terminal are hydrogen.

The relative quantities given off at the terminals can be measured by using a form of apparatus like that shown in Fig. 309. This is known as Hoffman's apparatus, and with it the hydrogen collected over the negative pole is shown to be twice the oxygen collected over the positive pole.

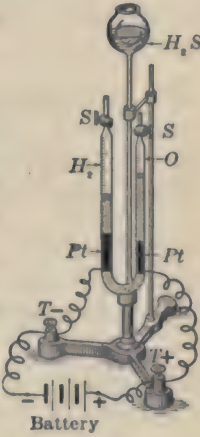


FIG. 309

The action of the current shown in the last two experiments is called *electrolysis*, and the solution in which this action goes on is an *electrolyte.* The apparatus used in electrolysis is called a *voltameter.* The parts into which the current separates the electrolyte are called *ions;* that which goes to the – electrode, or *cathode*, being called the *cathion;* and that which goes to the + electrode, the *anion.* From the direction which the ions take in the electrolyte their electric condition is determined; hence the cathion is considered electro-positive and the anion electro-negative.

366. Electrolysis of Copper Sulphate. — EXPERIMENT 188. — Send a current through a solution of copper sulphate placed in the U-tube, and it will be found that bubbles of oxygen rise from the anode, while the cathode will be coated with copper.

The action of the current in this experiment is to separate the $CuSO_4$ into Cu, which goes with the current toward the negative pole and is deposited upon it, and SO_4, which goes toward the positive pole, decomposing the H_2O of the solution, forming H_2SO_4, and setting free the oxygen at the pole.

If a copper anode is used, the SO_4 will unite with it, forming $CuSO_4$, keeping up the strength of the solution and eating away the copper. This property is made use of in purifying copper, for if a plate of impure copper is used as the anode, the copper deposited on the cathode will be pure, while the impurities will be left in the solution.

367. Electro-metallurgy. — The experiment just given is an example of what may be done in the electric deposition of metals. This method is in use commercially, and is found a most excellent one for purifying metals.

368. Electroplating is the process of coating one metal with another by means of the electric current. The article to be coated is coupled to the negative pole in the bath. Copper may be deposited from a bath of copper sulphate, silver from one of silver cyanide. Nickel plating is extensively used to protect articles made of brass, iron, or steel from oxidation.

369. Electrotyping. — The process of electrotyping is used to make copies of type, medals, or other objects. The object to be copied is thoroughly cleaned, and a mold is taken from it in plaster of paris, or wax. A careful dusting of the surface with some conducting substance, as graphite, is necessary ; then the mold is suspended in the proper solution by a wire from the – pole of a battery, the current is turned on, and the deposit begins. When the coating is thick enough so that it can be taken from the mold without bending, it is removed and backed by melted lead or type metal.

370. Secondary Batteries. — EXPERIMENT 189. — Couple a battery *B*, and a sulphuric acid voltameter *V*, as in Fig. 310. At the points *A* and *C* couple in a galvanometer, *G*. Put one key, *K*, in the main circuit, and another, *K'*, in the galvanometer circuit. Open *K'* and close *K* for a few seconds, letting the current pass through *V*. Then open *K* and close *K'*, and the galvanometer will show that a current is being sent out by *V*. The deflection of the galvanometer also shows by its direction that the current is coming out in a direction contrary to that in which it was sent through by the battery.

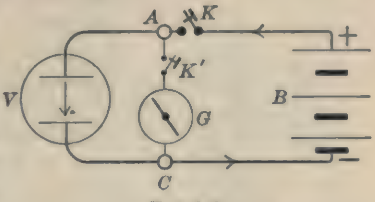


Fig. 310

Planté found that if lead plates are used as electrodes, and dilute sulphuric acid as liquid, an efficient form of battery for the storing of electrical energy is the result. In recent forms of this battery the lead plates, or *grids*, are grooved in such a form that the grooves can be filled with a paste of red oxide of lead for the positive plate, and litharge for the negative plate.

Such batteries are called *secondary batteries*, *storage cells*, or *accumulators*. Storage cells are very convenient for experimental work. Each has an E.M.F. of about 2 volts, and since their internal resistance is very small, they will give a large current if desired. They are also very constant in their voltage. Three or four cells will give voltage and current sufficient for most of the experimental work in this book.

371. Magnetic Effects. — Experiment 190. — Couple three or four cells in such a way that you will get a large current (series or parallel?) when the external circuit is a large copper wire. While the current is passing dip the wire into a mass of iron filings. On lifting the wire, filings will be found to cling to it.

From this experiment we see that a wire while carrying a current becomes a magnet.

Experiment 191. — Through the middle of a thick card with a smooth surface, like bristol board, thrust a piece of No. 12 copper wire. Connect the ends of this wire with a battery arranged to give its maximum current, and while the card is supported in a horizontal position, sift iron filings over it, and strike it lightly with a pencil. The filings will show that the wire is surrounded by magnetic lines of force acting in circles having the axis of the wire for their center. A small magnetic needle will set itself tangent to these circles at any point. If the current passes up the wire, as in Fig. 311, the direction of the lines of force is counter-clockwise. By the direction of the magnetic lines is meant the direction in which the + end of the magnetic needle will point. If the current is sent down the wire, then the direction of the lines of force will be clockwise.

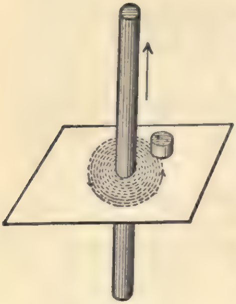


FIG. 311

372. The relation between the direction of the current flowing in a conductor and the direction of the resulting lines of magnetic force around it may be stated as follows: Grasp the conductor in the right hand, with the thumb pointing in the direction of the current; then the fingers will point in the direction of the lines of magnetic force.

EXPERIMENT 192. — Couple a battery to a straight wire *AB* (Fig. 312), and hold it above and parallel to a magnetic needle. The needle will turn from its position in the direction indicated in the figure. Place the wire *below* the needle, and the direction of its deflection is reversed. Change the direction of the current in the wire, and the needle is deflected as at first.

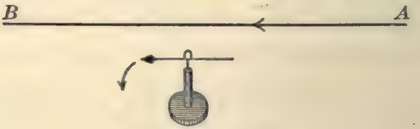


FIG. 312

This experiment is an important one, and shows the principle of one class of *galvanometers*. The relation between the direction of the current in the wire and the deflection of the *north* end of the needle is as follows: Place the right hand with the palm toward the needle and with the fingers extended in the direction of the current; then will the extended thumb point in the direction of the deflection of the needle.

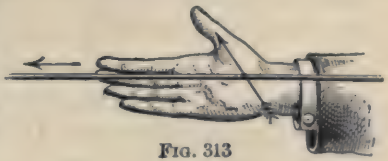


Fig. 313

373. Magnetic Properties of the Solenoid. — A *solenoid* is formed of a coil of insulated wire wound upon a cylinder in one or more layers. Its magnetic properties are shown in the following experiment.

Experiment 193. — Place upon a table a magnetic needle, and let it come to rest. Place a solenoid *S*, with one end about two inches from the north pole of the needle. Close the key *K*, sending the current through the solenoid, and the needle will be acted on at once, being either attracted or repelled according to the direction of the current in the coil.

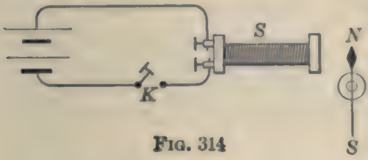


Fig. 314

The length of a solenoid is usually great compared with its diameter, but its magnetic properties are still retained even if it is shortened to a single turn.

Experiment 194. — Bend a piece of brass wire, No. 12, into a circle about six inches in diameter. Bend the ends nearly together and tie them to a wooden plug. Put a screw eye in this and suspend it by a thread after having soldered a small wire to each end of the ring. Connect these fine wires with a battery, and when the current is turned on the ring will come to rest in an east and

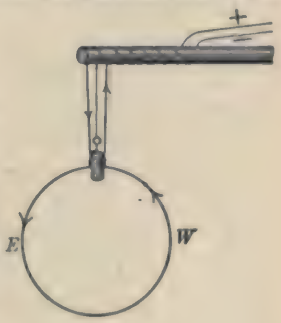


Fig. 315

west line. Present a bar magnet, and the ring will set itself at right angles to the magnet.

These experiments show that the solenoid, however short, has the properties of a magnet.

374. The Electro-magnet. — If the solenoid is provided with a soft iron core it becomes an electro-magnet. Since the iron offers a better path for the lines of force than air, that is, a path having less resistance, the introduction of the core increases the number of lines of force that a certain current will generate on passing through the coil.

375. Poles of an Electro-magnet. — When the ends of an electro-magnet are examined with the magnetic needle, it is found that the following rule holds: If the coil is grasped in the right hand with the fingers pointing in the direction of the current, then the thumb will point toward the north pole of the magnet.

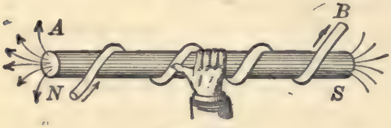


Fig. 316

376. The Horseshoe Electro-magnet. — Since the object to be attained in an electro-magnet is a strong magnetic field, the horseshoe form is the best. As commonly made it consists of two spools wound with insulated wire and mounted on two cylindrical cores, which are fixed perpendicularly into a yoke of soft iron. The wire is wound on the spools in such a

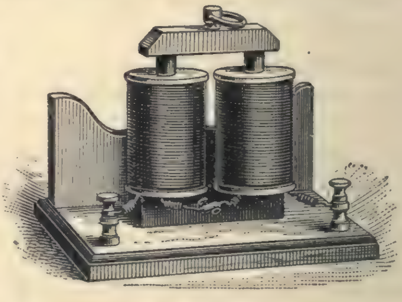


Fig. 317

way that if the cores and yoke were bent out into a straight line the winding would be all in one direction. The core of an electro-magnet should be of such a quality of iron that it will lose its magnetism or became demagnetized as soon as the current is stopped. If there is a small amount of residual magnetism in it after the current is cut off, so that it will not release the armature promptly, paper can be pasted over the ends of the magnet to help overcome this defect. Annealing the cores will sometimes remove the difficulty.

PRACTICAL QUESTIONS AND PROBLEMS

1. How many lesser calories will be developed by a 10-ampere current flowing for half an hour through a resistance of 18 ohms?

2. The 110-volt lamp requires a current of .5 ampere and has a hot resistance of 220 ohms. How much heat will be generated in such a lamp per hour?

3. Suppose a German silver wire, the resistance of which is 3.5 ohms, to be immersed in 3 liters of water at 20° C. What will be its temperature after a current of 4 amperes has been passing through it for 20 minutes?

4. A current of 1 ampere deposits .00032959 gram of copper per second on the negative plate of a copper voltameter. What current will be required to deposit 10 grams in two hours?

5. Suppose a tin can to be used to hold the copper sulphate solution, and the negative wire from the battery to be joined to it. How much copper will be deposited on its inner surface in an hour, with a current of 4 amperes?

6. Why can a greater current be obtained from a storage cell than from a primary cell?

LABORATORY WORK

1. Fit a cork stopper to a glass beaker. Solder a spiral of German silver wire No. 24 to short pieces of copper wire No. 16 arranged as terminals (Fig. 318), passing through the cork. Insert a thermometer through a hole in the middle of the cork. Put 250 c.c. of water into the beaker, and send a current through the wire. Take readings of the thermometer at uniform intervals. From this determine the number of heat units generated by the current in a given time.

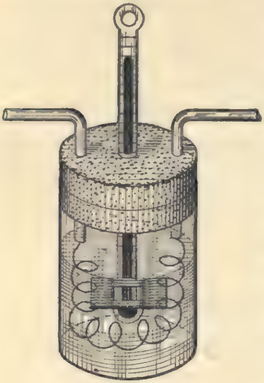


FIG. 318

2. Make a wooden frame about half an inch high that will fit closely around the edges of a copper plate from which calling cards have been printed. Wash the plate until it is perfectly clean, and place it in the frame. Mix plaster of Paris with water until it can be poured readily, and pour it about a quarter of an inch deep over the plate, being careful that no air bubbles remain. Dry thoroughly and remove the cast. Coat the face of it with graphite, and suspend it from the negative pole of a battery in a solution of copper sulphate, with the face of the cast turned toward the copper plate which forms the positive pole. When the deposit is as thick as a sheet of paper remove it from the cast and back it up with lead. The deposit should be so thick that it will not bend when it is taken off.

3. Select a bottle about 6 inches in diameter, with a wide mouth. Cut it in two in the middle by filing a notch in one side, and then starting a crack from this notch with the heated point of a brass rod and leading it entirely around the bottle. Fit the mouth with a cork, and pass through this two rubber-covered wires with platinum terminals. Fill the bottle two thirds full of acidulated water; fill two long test tubes with this water and invert, one over each terminal. Send a current through this water voltameter, and measure the gas that comes off from each terminal.

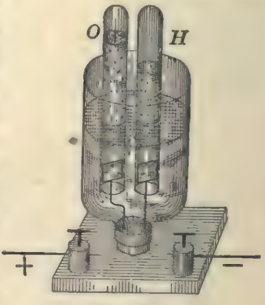


FIG. 319

This can be done easily by calibrating the test tubes with mercury before the experiment. To do this close one end of a thick-walled glass tube in the Bunsen flame, and grind off the other end until it will hold just a cubic centimeter when a glass plate is slipped over the mouth. Fill this with mercury and pour it into the tube, marking the height for every cubic centimeter.

Is the proportion of hydrogen to oxygen collected the same as in the composition of water?

Fig. 320

4. Dissolve two grams of potassium iodide in hot water, and add to the solution a little boiled starch. Solder a tin plate to a wire and connect it with the negative pole of a battery. Moisten a sheet of paper with the iodide solution and lay it upon the tin plate, and, with the end of a wire attached to the positive pole of the battery, write on the moistened paper. Every touch of the wire will make a purple mark caused by the starch acting upon the iodine set free by the decomposing action of the current.

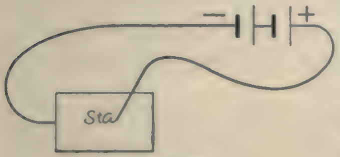


Fig. 321

This is the principle of a very rapid and efficient method of receiving telegraphic messages automatically.

5. Make an electro-magnet by winding several layers of insulated copper wire No. 16 around a wooden spool about a foot long, and putting a piece of gas pipe or soft iron rod inside the spool for a core. Couple with several cells of a battery, and when the current is turned on, dip the end of the core into a mass of nails; lift the magnet and note the effect as in Fig. 322. Break the current. What is the result?

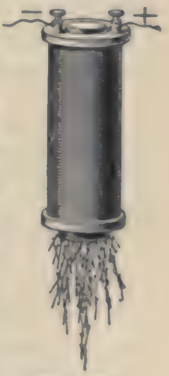


Fig. 322

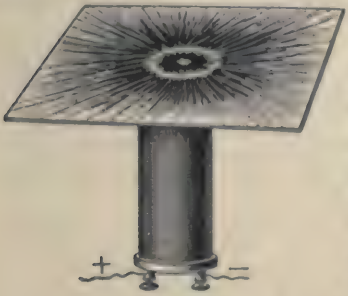


Fig. 323

6. Support the same magnet vertically, and lay over the upper end a sheet of glass (Fig. 323), upon the under side of which a sheet of paper has been pasted. Sift over the plate an even layer of iron filings, and, tapping the plate lightly, turn on the current. The lines of force will be shown in a striking manner.

7. Fasten an electro-magnet to a baseboard and support its armature from the short arm of a balance, while a movable weight is hung from the long arm, as in Fig. 324. Determine the weight that must be placed on the armature to balance the long arm. This amount must be added to all readings. Send a current of 1 ampere through the electro-magnet, and find the weight required to pull off the armature. Determine the weight for 2 amperes. Continue, increasing the current 1 ampere each time, up to 10 amperes. Construct a curve with amperes laid off along the axis of X, and the pull on the armature along the axis of Y.

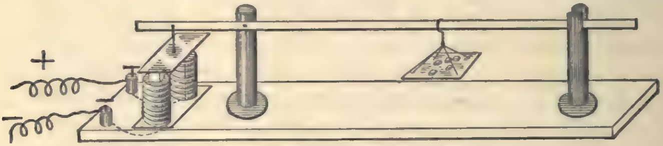


Fig. 324

Note. — The wire on the electro-magnet will need to be rather large, not to overheat.

IV. Electrical Measurements

377. Electrical Quantities. — The three quantities most necessary to measure in electricity are *current*, *electromotive force* and *resistance.*

378. The Unit of Current, the Ampere. — Either the chemical, magnetic, or heating effects may be taken as a basis for measurement of currents. The chemical effect, however, is taken to define the unit, and the magnetic effect for practical use.

The *ampere* is that current that will deposit .001118 g. (.01725 grain) of silver per second from a solution of silver nitrate. The same current will deposit .00032959 g.

(.005086 grain) of copper per second from a solution of copper sulphate.

It is evident that this method is not adapted to measurement unless the current can be kept uniform for a considerable time. This method is the one used for measuring the current supplied for lighting in the instrument known as the Edison current-meter. This current-meter consists of a zinc voltameter which, by the increase in the weight of the negative plate, determines the average current used.

For the measurement of small currents the *milliampere*, or thousandth part of an ampere, is used as a unit.

379. The Unit of Resistance. — The *ohm* is defined as the resistance of a column of mercury whose mass is 14.4521 g. and which has constant cross section, and a length of 106.3 ± cm. at 0° C. This amounts practically to a column 106.3 cm. long and 1 sq. mm. in cross section. Ten feet of No. 30 copper wire has a resistance of 1.04 ohms.

A *megohm* is a million ohms. A *microhm* is one millionth of an ohm.

380. The Laws of Resistance. — The resistance of a conductor depends upon four things: *length*, *cross section*, *material*, and *temperature*. Experiment has determined the following laws:

I. *The resistance of a conductor is directly proportional to its length.*

II. *The resistance of a conductor is inversely proportional to its cross section.* — In a wire, therefore, the resistance is inversely proportional to the square of the diameter of the wire.

III. *The resistance of a conductor depends upon its material and molecular condition.*

IV. *The resistance of a metallic conductor increases as its temperature rises. The resistance of carbon and electrolytes, on the other hand, decreases.*

This property of carbon is a very valuable one in incandescent lamps, as the hot resistance of a lamp is only about two thirds of its cold resistance.

The per cent increase in the resistance of a wire, per degree change in temperature, is called its *temperature coefficient.*

The first three laws may be expressed by the formula

$$R = K\frac{l}{d^2}. \tag{57}$$

In this formula l is in feet, d in thousandths of an inch or *mils*, and K is a constant that depends upon the material and molecular condition, and is of such a value that R is given in ohms.

Values of K at 75° F.

Silver	9.76	Platinum	58.80
Copper	10.38	Iron	63.08
Aluminum	19.00	German silver	135.92

381. Unit of Electro-Motive Force, the Volt.—The *volt* is the difference of potential required at the ends of a conductor, the resistance of which is 1 ohm, to send through it a current of 1 ampere.

The E.M.F. of a cell depends only upon the materials of which it is composed, and not at all upon its size or shape. The gravity cell gives nearly 1.1 volts; the Leclanché cell 1.5 volts, and the chromic acid cell about 2 volts. Many attempts have been made to produce a standard cell. In such a cell it is not at all essential that the E.M.F. should be 1, but that the E.M.F., whatever it is, should remain constant. The Carhart-Clark standard cell has an E.M.F. of 1.44 volts at 15° C.

382. Instruments used in Measurements; the Tangent Galvanometer. — The principle of one form of galvanometer has already been shown in Experiment 192. If the conducting wire is carried in the circumference of a circle entirely around the needle so that its diameter is ten or twelve times the length of the needle, the instrument is a *tangent galvanometer.* In instruments of this kind the current is proportional, not to the angle through which the needle turns, but to the tangent of the angle. For example, if the current c gave a deflection of 20°, and the current c' one of 40°, c' would not be twice c, but its value would be expressed by the proportion

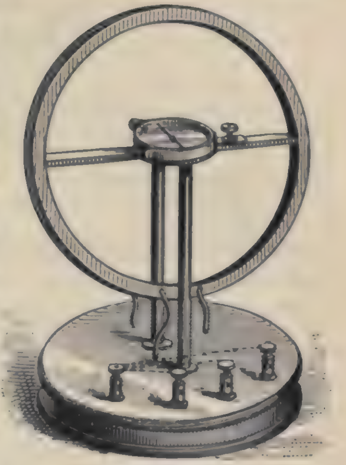


FIG. 325

$$c : c' = \tan\ 20° : \tan\ 40°$$

or

$$c : c' = .364 : .839$$

hence

$$c' = \frac{.839\,c}{.364} = 2.3\,c$$

383. The Astatic Galvanometer. — For the measurement of small currents a delicate galvanometer is needed. The form known as the *astatic galvanometer* is frequently used. It is made by fixing two similar needles to a vertical bar in such a way that the needles point in opposite directions, and arranging the coil with one branch between the needles and with the other below both (Fig. 326). When the needles are of nearly the same magnetic strength, a very slight force throws them out of their north and south position. Both branches of the coil act upon both needles. It is an interesting problem to consider the effect of each branch upon each needle and find the combined effect. Let the student work out this problem.

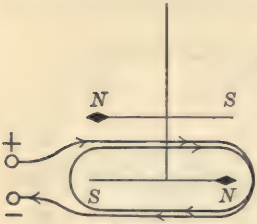


FIG. 326

384. The Solenoid Galvanometer. — A second principle used in the construction of galvanometers is that which determines the following phenomenon: If an iron rod is suspended with one end inside a coil of wire, the rod will be pulled into the coil as soon as a current is sent through the wire. If the scale shown in Fig. 327 is properly calibrated, the instrument becomes a current-measurer or *ammeter*. Many instruments for use in electrical stations are of this type.

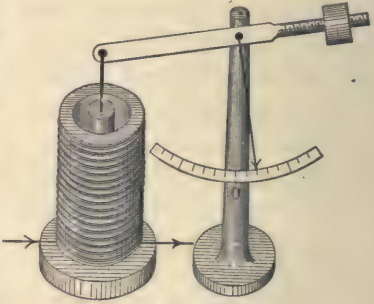


FIG. 327

385. The d'Arsonval Galvanometer. — A third principle used in the construction of galvanometers — a most important one — is employed in the instrument shown in Fig. 328. Between the poles of a horseshoe magnet placed vertically there is fixed an iron cylinder *I*. A coil of fine wire wound on a rectangular former is suspended from the point *A*, so that it will swing freely between the cylinder and the magnet poles. When a current is sent through it, the coil becomes a magnet with its poles in a line at right angles to the plane of the horseshoe magnet, and at once, because of the influence of the horseshoe magnet, it is deflected. The controlling force is the torsion of the wire supporting the coil. The readings are taken either from a pointer and scale, or from the reflection of a fixed scale from a mirror fastened to the coil at the point *C*. This instrument has the advantage of being dead beat, that is, it will come to rest quickly without vibrations.

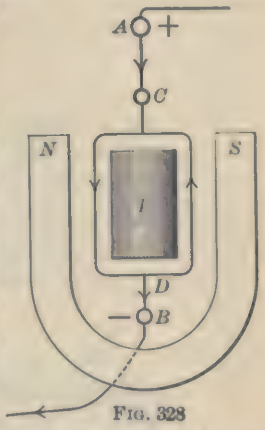


FIG. 328

386. The Weston Ammeter and Voltmeter are made on the principle of the d'Arsonval galvanometer, but are very compact and portable, besides being sensitive and accurate. The zero is at one end of the scale, hence the current can be sent through them in but one direction. A mirror placed beneath the needle prevents parallax in reading when the image is made to coincide with the needle itself. The voltmeter is shown in Fig. 329.

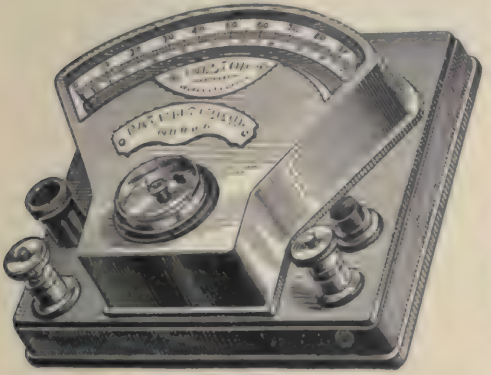


FIG. 329

The ammeter is the same in principle as the voltmeter, the resistance, however, being very low in the ammeter and high in the voltmeter. The calibration of the instrument is such that the amperes or volts are read directly.

387. The Resistance Box. — In the measurement of resistance a standard of resistance must be used for comparison. This standard is usually made of coils of resistance wire contained in a box like that shown in Fig. 330. For all coils except those that are of very small resistance, a wire is used that has a high specific resistance, *i.e.* one in which the value of K (p. 318) is high. German silver is frequently used. For all coils, however, it is best to use a wire that has a low temperature coefficient. An alloy called platinoid, which has a temperature coefficient less than half that of German silver, is coming into general use. When the terminals of the battery are connected with the binding posts of the box, the amount of resistance introduced into the circuit is determined by the number of plugs that are taken out. If all the plugs

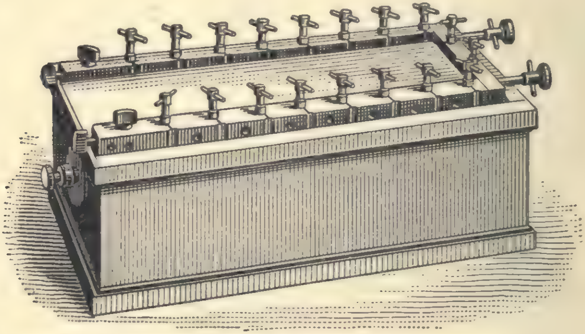


Fig. 330

are in the box the resistance is practically zero. If the plug corresponding to the 10-ohm coil is pulled out, the current, in going from the brass piece *A* to the piece *B* (Fig. 331), must go through that coil, so that the resistance is 10 ohms. The resistances are generally .1, .1, .2, .3, and .4 ohm; 1, 2, 3, and 4 ohms; 10, 20, 30, and 40 ohms; and 100, 200, 300, and 400 ohms. This makes it possible to introduce any number of ohms from .1 ohm to 1111.1 ohms. The coils are wound as shown at (*a*) in Fig. 331, to keep the coil from being a magnet as soon as a current passes through it, and also to prevent what is called self-induction.

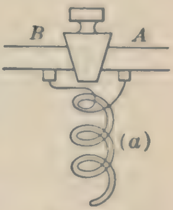


Fig. 331

388. The Measurement of Resistance. — (*a*) *By the Substitution Method.* — Experiment 195. — Near one end of a board 18 inches long and 5 inches wide, as at *C* (Fig. 332), fix three binding posts connected beneath the board, as in the figure. Near the other end, *A*, fix a switch so that the current can be sent either through the resistance *R*, to be measured, or through *B*, the resistance box. Couple a galvanometer, *G*, between *C* and one pole of the battery. Send the current through *R* and note the deflection of the galvanometer. Pull out a plug from the resistance box — the 10-ohm plug,

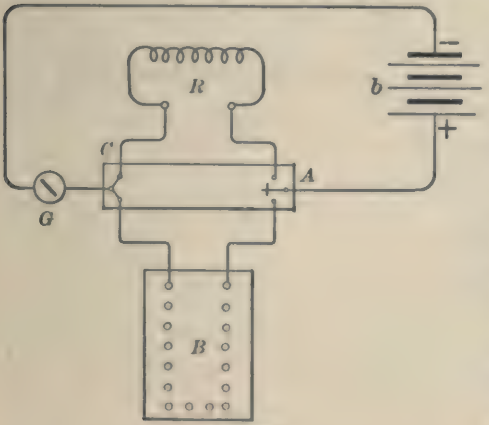


Fig. 332

for example,—throw the current through the box by the switch, and note the deflection. If it is increased, introduce more resistance from the box, and *vice versa*, until the reading of the galvanometer is the same as before. Now throw the current from one circuit to the other by the switch *A*, and if the reading is unchanged, the resistance of *R* and *B* must be the same. Care should be taken to have the leading wires from *A* and *C* to both *B* and *R* the same in length and diameter.

Experiment 196.—Couple two galvanometers, as nearly alike as possible, in series with a resistance box (Fig. 333). Send a current through them and compare their readings. Vary the resistance in the box and send different currents through, recording the reading of each galvanometer. This gives their comparative readings for the same currents.

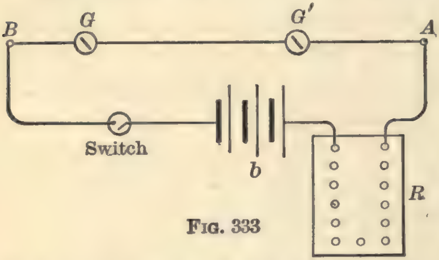


Fig. 333

Experiment 197.—Couple the galvanometer *G*, used in Experiment 196, by two pieces of copper wire, No. 16, five feet long, to the binding posts *A* and *B* (Fig. 334). Couple the galvanometer *G′* by two pieces of copper wire, No. 30, five feet long, to the same binding posts. Couple a battery, resistance box, and switch, as in the figure, to *A* and *B*. Send different currents through the circuit by varying the resistance in the box, and observe that the current as indicated by the galvanometers is always the greater in the No. 16 wire. Why?

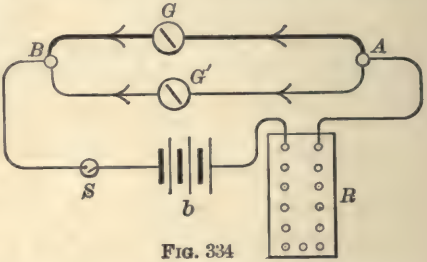


Fig. 334

389. (*b*) *The Method of the Wheatstone Bridge.*—The circuit from the point *A* to the point *B* in the last experiment is called a ***shunt circuit***, or a *parallel circuit.*

Wheatstone has made use of the fall of potential in parallel circuits for the measurement of resistance. When two points *A* and *B* (Fig. 335) are connected by two parallel circuits, it is evident that the total fall of potential in the upper branch *AxB* is equal to the total fall in the lower branch *AyB*. It is also evident that there must be a point *y* in the lower branch where the fall of potential from *A* is exactly the same as the fall of potential in the upper branch from *A* to *x*; so that the points *x* and *y* will have the same potential. If, then, the points *x* and *y* are connected by a wire, no current will flow in the wire. If, however, a wire is connected from *x* to a point *z* between *A* and *y*, the current will flow from *z* to *x*. If the connection is made to a point *w*, between *y* and *B*, the flow will be from *x* to *w*. By the introduction of a galvanometer in the conductor *xy*, the proper position for *y* can readily be determined, and when this is found, then (Fig. 336) the resistance of *Ax* : the resistance of *xB* = the resistance of *Ay* : the resistance of *yB*.

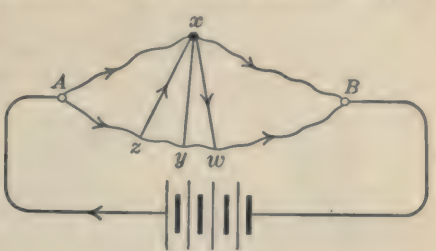


FIG. 335

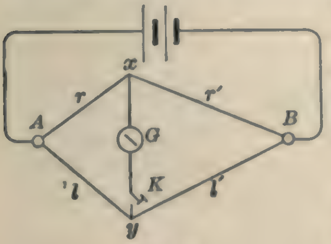


FIG. 336

In the *Wheatstone bridge* (Fig. 336) the circuit *AyB* is a single wire of uniform diameter; hence its resistance is proportional to its length, and the proportion becomes $r : r' = l : l'$. At the point *y* is a key *K*, by which contact with the wire is made, and the position of y determined. For r' is put the resistance box, while r is the resistance to be measured.

The above is a method that has come into general use. A common form of bridge is shown in Fig. 337. For accurate measurement the galvanometer needs to be a mirror galvanometer, while the deflections should be read with a telescope and scale.

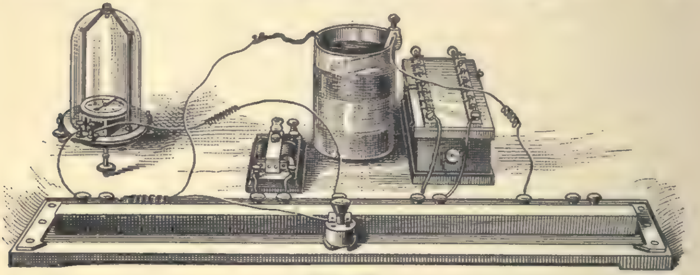


Fig. 337

390. (*c*) *The Fall of Potential Method* is a method in which the only instruments needed are an ammeter and a voltmeter. For this reason it is well adapted to the requirements of practical electricians.

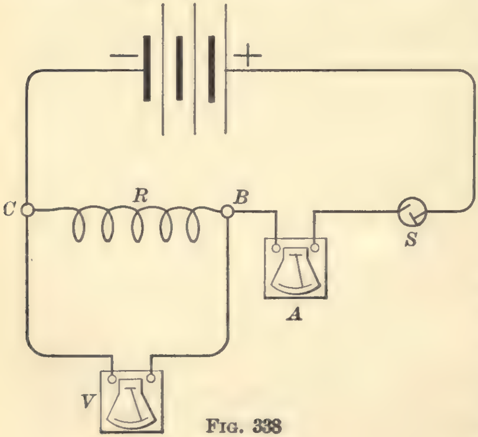


Fig. 338

Experiment 198. — Couple an ammeter A (Fig. 338) in series with the resistance R to be measured. To the terminals B and C of this resistance couple a voltmeter V, as a shunt. Make the current by the switch S, and read both instruments at the same time. Substitute these readings in

$$R = \frac{E}{C} = \frac{V}{A},$$

derived from Ohm's Law, and the value of R is determined.

It is to be observed that the reading of the ammeter gives the sum of the currents through the resistance R and through the voltmeter. The following experiment shows how this may be corrected, although, on account of the high resistance of the voltmeter, the current will usually be so small that it may be neglected.

Experiment 199. — Use the same apparatus as in the preceding experiment, but couple as in Fig. 339, putting the voltmeter as a shunt to both the resistance to be measured and the ammeter. Take simultaneous readings of the two instruments as before, and find the resistance, which will now include the resistance of the ammeter. This can be measured by the bridge, if not already known, and subtracted from the resistance of both, and the difference will be the resistance of R.

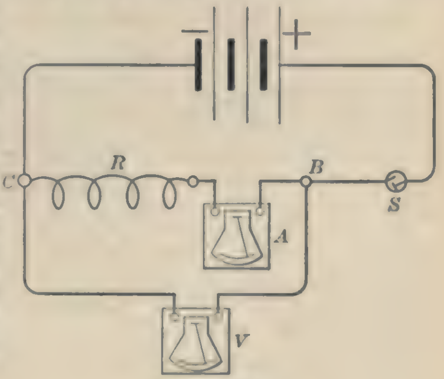


Fig. 339

391. Combined Resistance of Parallel Circuits. — The combined resistance of two or more conductors in parallel is always less than that of either conductor. The reason for this is evident when we consider the expression for the resistance of a conductor, $R = K\frac{l}{d^2}$. The putting of two wires in parallel is equivalent to increasing the diameter of one of them.

Experiment 200. — Fasten two pieces of brass or tin, *A* and *B* (Fig. 340), to a board, a number of feet apart, — ten, if possible, — and fit a binding post to each. Make five holes along the edge of each, and screw through each hole a round-headed wood screw; stretch a copper wire (*a*), No. 30, between the two pieces, and fasten it with the two upper screws. Measure the resistance between *A* and *B*. Add a second wire (*b*) of the same size, and measure the resistance between *A* and *B*. Put in a third wire (*c*), and again measure. Add in succession a No. 24 wire (*d*) and a No. 16 wire (*e*). Remove all the wires except *e*, and measure again.

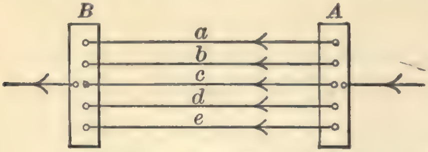


Fig. 340

A careful study of the results of the above experiment will help the student to understand the conditions which govern the resistance of parallel circuits.

To find an expression for the combined resistance of a circuit and its shunt, we can take the case of a galvanometer with its shunt (Fig. 341). The current passing through the galvanometer may be written $G = \frac{V}{g}$, in which *G* is the current, *g* the resistance of the galvanometer, and *V* the potential difference at its terminals.

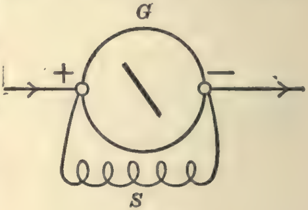


Fig. 341

The current through the shunt may be written $S = \frac{V}{s}$. The entire current will be $C = \frac{V}{R}$, in which *R* is the combined resistance of the galvanometer and its shunt.

Since $C = G + S$,

$$\frac{V}{R} = \frac{V}{g} + \frac{V}{s}, \text{ and } \frac{1}{R} = \frac{1}{g} + \frac{1}{s}; \text{ or, } R = \frac{gs}{g+s}. \quad (58)$$

When there are several circuits with resistances r, r', r'', r''', etc., their combined resistance will be found by solving:

$$\frac{1}{R}=\frac{1}{r}+\frac{1}{r'}+\frac{1}{r''}+\frac{1}{r'''}, \text{ etc.}$$

The arrangement shown in Fig. 341 is frequently used when we wish to measure a current greater than the galvanometer will carry safely. A shunt that will carry $\frac{9}{10}$ of the current, so that the galvanometer will read $\frac{1}{10}$ of the true value of the current, is called a *tenth shunt.*

392. The Resistance of Batteries. — The determination of the resistance of a battery is more difficult than that of a wire, because this resistance is different at different times, on account of polarization, etc. *Mance's method* is a good one; it consists in putting the cell, the resistance of which is to be measured, in one arm of a Wheatstone bridge, coupling as in Fig. 342, and so adjusting the resistance that there shall be no change in the deflection of the galvanometer when the key is closed. When this condition is fulfilled the resistance of the cell is given by the expression

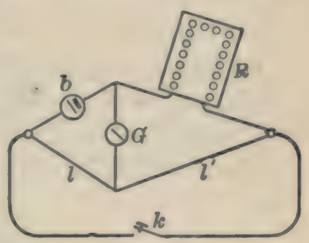


FIG. 342

$$b=\frac{lR}{l'}.$$

393. The Measurement of Current. — Currents of electricity are generally measured by some form of galvanometer. When the relation between the current passing through a galvanometer and the corresponding deflection has been experimentally determined, the galvanometer is said to be calibrated. A galvanometer can be calibrated by measuring the fall of potential through it after having measured its resistance.

When a galvanometer has been calibrated to read in amperes it is called an *ammeter*. The ammeter is usually of very small resistance, and is put in series in the circuit.

394. The Measurement of E.M.F. — Electro-motive force, or, more properly, difference of potential, is also measured with a galvanometer, but this is generally of high resistance, and, if calibrated to read volts, is called a *voltmeter*. But a small part of the current passing between the points, the potential difference of which is to be measured, passes through the voltmeter, and consequently voltmeters are put as a shunt to the circuit.

For the measurement of E.M.F. an instrument called an *electrometer* is also used.

395. The Watt. — When a difference of potential at the terminals of a circuit is 1 volt and this sends a current of 1 ampere through the circuit, the power developed is called a *watt*. The watt is $\frac{1}{746}$ of a horse power and develops 44.24 foot pounds of mechanical energy per minute. In any circuit the watts equal volts × amperes; *i.e.* $W = VA$.

PRACTICAL QUESTIONS AND PROBLEMS

1. For how long a time must a current of 5 amperes flow through a copper voltameter to deposit 21 g. of copper?

2. Ten grams of silver is to be deposited upon a certain surface. How long will it take a current of 8 amperes to do it?

3. What is the resistance of a half-mile of copper wire with a diameter of .0508 in.?

4. Find the resistance of an iron wire of the same dimensions.

5. The hot resistance of a 110-volt incandescent lamp is 220 ohms. Find the resistance of 2, 3, 4, and 5 lamps in parallel.

6. Two points, A and B, are connected by two conductors; when used separately, one of these has a resistance of 8 ohms, and the other of 14. Find the combined resistance of the two in parallel.

7. What is the combined parallel resistance of three wires having resistances of 4, 9, and 27 ohms, respectively?

8. What is the resistance of a circuit having a potential difference of 18 volts at its terminals, when a current of 4.2 amperes is passing through it?

9. A galvanometer has a resistance of 31.7 ohms. What must be the resistance of a tenth shunt for it?

10. Suppose the lamps mentioned in No. 5 are 16 candle power. How many watts will each lamp require? How many watts per candle power?

11. What current must be sent through a 50-volt lamp to produce 16 candle power? What will be the resistance of the lamp?

12. A certain arc lamp requires a current of 10 amperes and the fall of potential through the lamp is 45 volts. How many watts are required to run it?

13. What is the electrical horse power of a dynamo that gives a current of 200 amperes at 110 volts?

14. An inclosed arc lamp requires a current of 4.5 amperes, and a difference of potential at its terminals of 80 volts. How many watts does it require? What is its resistance? What resistance must be put in series with it to couple it to a 110-volt circuit? Make a drawing showing how you would couple it.

LABORATORY WORK

1. Prove that the size of the cell does not determine its voltage. Couple a voltmeter to a plunge cell and read the voltage both when the zinc plate is just touching the liquid and when it is all below the surface.

2. Prove that the size of a cell does determine the current it will send, by making the same experiment with an ammeter.

3. Wind a coil 6 in. long, putting on six layers of No. 16 insulated copper wire. Suspend an iron rod from a spiral spring, so that its lower end will extend about an inch inside the coil, when it stands vertically. Put a glass bead on the wire that fastens the spring to the rod, and back of it place a vertical scale. Couple it in series with a battery, resistance box, and ammeter. Make a curve showing the relation between the currents and the distance the iron rod is drawn inside the coil.

4. Make a lamp resistance board as follows: Lead, in grooves on the under side of the board, two copper wires, No. 16, from two binding posts at one end of the board to the other end of it. Solder short pieces of wire to these leading wires and couple them to the lamp bases. Put into these bases lamps of various resistances, and measure each separately. Measure them in groups of two, and compare the measured resistance with that calculated from the formula for the combined resistances of parallel circuits.

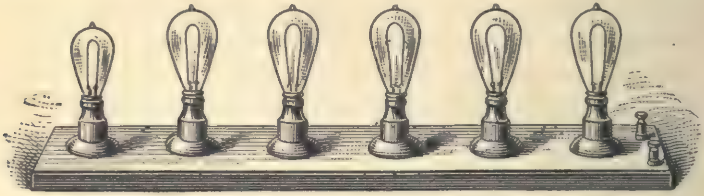


Fig. 343

5. Put lamps of the same resistance in the board. Measure the resistance of one, two, three, four, etc., and from the results show how, when the proper voltage is supplied, — 110 for example, — each lamp will have its required current, however many are turned on.

6. Measure the resistance of a galvanometer and then find the length of wire that must be used for a tenth shunt. Couple the galvanometer to a gravity cell and notice the deflection. Put in the shunt and couple the shunted galvanometer to the same cell. What is the relation between the deflections?

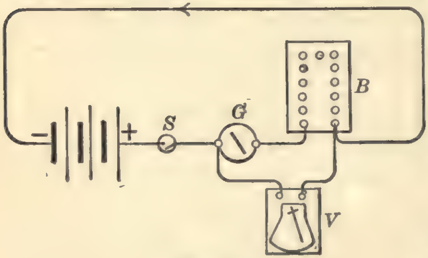


Fig. 344

7. Couple three or four cells of a gravity battery in series with a switch, galvanometer, and resistance box as in Fig. 344. Couple a voltmeter as a shunt to the galvanometer and resistance box. Tabulate the results as follows:

V.	$g+R$.	$C=\frac{V}{g+R}$	D.
1.3	2.6	.5	4°

In this table

V = the reading of the voltmeter;

g = the resistance of the galvanometer;

R = the resistance of the box;

D = the deflection in degrees.

C is calculated from Ohm's Law.

Make a curve, laying off currents on the axis of X, and deflections on the axis of Y.

This experiment *calibrates* the galvanometer, and the curve is the *calibration curve.* From this curve the current corresponding to any deflection can be easily read off.

V. INDUCED CURRENTS AND THE DYNAMO

396. Parallel Currents. — EXPERIMENT 201. — Wind a spiral 3 cm. in diameter, of about fifteen turns of No. 24 insulated copper wire. Suspend it from a rod and couple the upper end to the + pole of a battery. Straighten out a short piece of the lower end of the coil and let it dip into a drop of mercury, which is connected with the − pole of the battery. When the current is turned on, the spiral will shorten and lift the end from the mercury. A spark will pass, then the spiral will lengthen, the point will again touch the mercury, and the action will be repeated. Why?

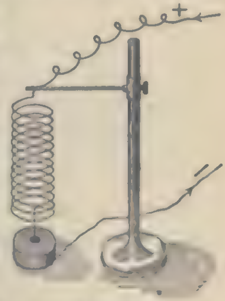


FIG. 345

This experiment shows, in a simple way, one result of the mutual action of parallel currents. Experiment has proved the truth of the following laws:

1. *Parallel currents flowing in the same direction attract each other.*

II. *Parallel currents flowing in opposite directions repel each other.*

III. *Currents making an angle with each other are attracted if both flow toward or away from the angle.*

IV. *Currents making an angle with each other are repelled if one flows toward and the other away from the angle.*

397. Induced Currents. — Experiment 202. — Make a coil of insulated copper wire No. 30, that will slide easily over a long bar magnet, and couple it to a sensitive galvanometer. Place the coil around the magnet at the middle, and, when the needle of the galvanometer is quiet, suddenly slip the coil off the + end of the magnet. The galvanometer will give a sudden throw and then gradually come to rest at zero. Place the coil again at the middle of the magnet, and slip it off over the – end. Again there will be a throw of the needle, but in the opposite direction. Taking the magnet in one hand and the coil in the other, slip the coil *on* the magnet from the – end. Note the direction of the deflection. Again, slip the coil *on* the magnet from the + end, and notice the direction of the deflection.

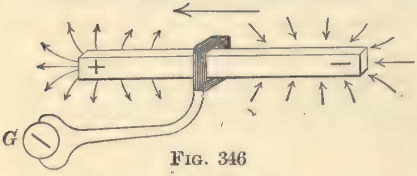


Fig. 346

The currents produced in this experiment are *induced currents* and they are produced by *cutting magnetic lines of force by an electrical conductor.* The experiment has shown that the currents produced depend for their direction upon the direction in which the conductor cuts the lines of force. By varying the speed of slipping off the coil

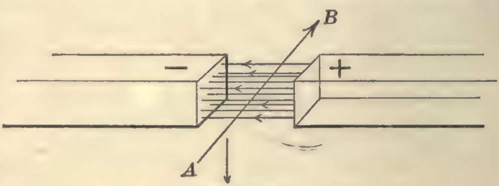


Fig. 347

we shall find that the amount of current depends upon the number of lines cut in a given time. The relation between the direction of motion of the conductor, the direction of the lines of force, and the direction of the induced current, is shown in Fig. 347. If a conductor *AB* is held horizontally and allowed to fall in a magnetic field cutting the lines of force as shown, then there will be set up at the ends *A* and *B* a difference of potential which will tend to send the current from *A* to *B*.

This law, which is an important one, may be stated as follows:

If a person, holding a conductor horizontally, stands at a + pole looking in the direction of the lines of force, and lets the conductor fall, the induced current will then flow toward the right hand.

EXPERIMENT 203. — Couple a coil of small insulated wire, called a secondary coil, to the galvanometer used in the last experiment.

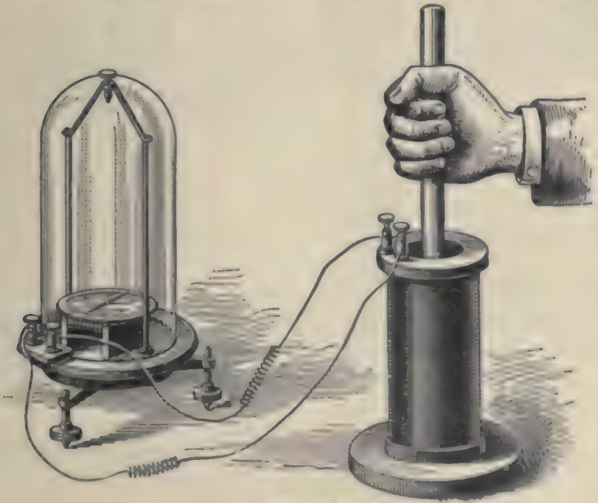


FIG. 348

Thrust the + end of a long bar magnet into the coil (Fig. 348), and observe the throw of the needle. Pull the + end out suddenly and compare the throw with that obtained at first. Repeat both experiments with the − end of the magnet.

This experiment, compared with Experiment 202, shows that it makes no difference whether the coil or the magnet is moved. *A current is induced whenever magnetic lines of force are cut by the wires.*

Experiment 204. — Take a coil of large wire, called a primary coil, of such a size that it will easily go inside the secondary, and connect it with a battery. Thrust it into the secondary coil as you did the bar magnet in the last experiment, and the same results will be obtained. Why?

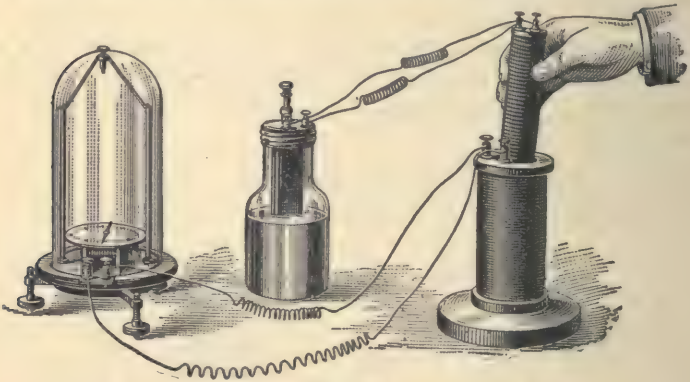


Fig. 349

Experiment 205. — Place the primary coil inside the secondary and introduce a switch between the primary and the battery. Make the circuit and notice the deflection. Break the circuit and again notice the deflection. Compare the directions of these deflections with those obtained in the last experiment, and explain.

Experiment 206. — Vary Experiment 205 by introducing a resistance box between the primary coil and its battery, instead of the switch. When a steady current is allowed to pass, there will be no deflection of the galvanometer. If the amount of current in the primary is changed, however, either increased or diminished, the throw of the needle will show the existence of an induced current.

Experiment has shown that the following laws for induced currents hold true:

I. *Whenever the current in the primary coil is either made or increased, there is induced in the secondary a current in the opposite direction.*

II. *Whenever the current in the primary coil is either broken or diminished, there is induced in the secondary a current in the same direction.*

398. Self-induction. — We have just seen that a change in the current in one coil induces a current in a second coil near the first. It is evident that a change of current in one turn of a coil should also induce currents in adjacent turns of the same coil. This effect is called *self-induction*, and its existence can be shown as follows:

EXPERIMENT 207. — Couple a battery, switch, galvanometer, and coil, as shown in Fig. 350. Turn on the current, and observe the direction of the deflection. Bring the needle back to zero, and keep it there by placing a cork at one side to stop it. Break the current, and notice that there is a throw of the galvanometer in the opposite direction, showing that the current induced in the coil is in the same direction as the current sent by the battery.

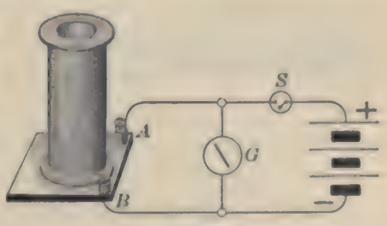


FIG. 350

399. The Induction Coil. — The *induction* or *Ruhmkorff coil* is a combination of coils used for the purpose of getting induced currents of high potential difference. A general view of one form of this coil is shown in Fig. 351. Fig. 352 is diagrammatic, showing the relation of the parts.

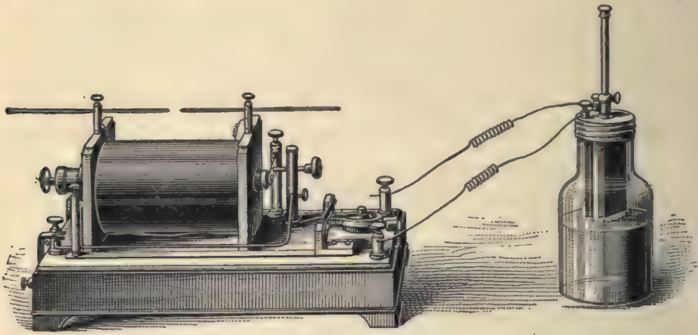


FIG. 351

The essential parts are a soft iron core, a primary coil with a few turns of large insulated wire connected with the battery, a secondary coil of a great many turns of fine insulated wire connected with binding posts *A* and *B*, an automatic make and break arrangement between the primary coil and the battery, a condenser connected with the primary circuit on each side of the break point *P*, and a switch to make and break the current.

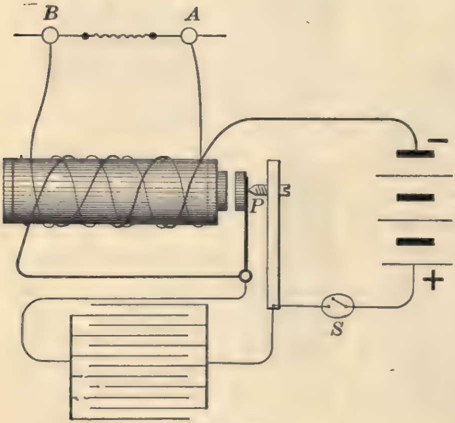


FIG. 352

The operation of the coil is as follows: When the switch is turned on, the current passes through the primary and makes a magnet of the iron core. This attracts the soft iron armature, which is fastened to a vertical spring, and breaks the current at *P*. As soon as this is done, the core is no longer a magnet, the armature is thrown back by the spring, the contact is again made at *P*, and the action is repeated. When the current is made in the primary coil, a current in the opposite direction is induced in the secondary, and when the current in the primary is broken, there is an induced current in the same direction in the secondary. The self-induction of the primary when the current is made acts against the battery current flowing in it, and reduces the induced E.M.F. in the secondary; but when the current is broken, the self-induction acts with the battery current and increases the E.M.F. of the secondary. The effect of the condenser is to increase the capacity of the primary coil and to shorten the time of breaking, thus raising the E.M.F. of the secondary. It also discharges through the battery, immediately after the current is broken, in a direction contrary to the battery current; this helps to demagnetize the core quickly.

The difference of potential necessary to give a spark 1 cm. long across an air gap between two parallel plates is given by Lord Kelvin as 30,000 volts.

Since the E.M.F. rises so high in an induction coil, it is evident that the insulation must be as nearly perfect as possible. In the most modern coils the secondary is wound in sections, and these thoroughly coated with insulating wax under conditions that secure the removal of all air.

A very effective mechanical device for making a quick break in the primary circuit is shown in Fig. 353. Instead of the break being made by the spring attached to the vibrating armature, it is made at the point *P* by a second vibrating spring which normally holds the parts in contact. In the old form of the coil the break takes place from a position of rest, but in this form the armature is in the middle of its swing when the break is made.

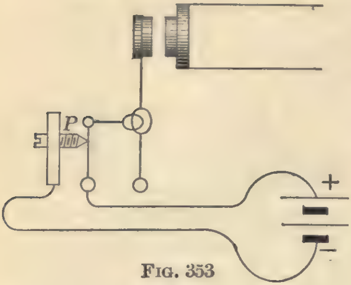


Fig. 353

A somewhat novel form of interrupter is shown in Fig. 354. This is known as the Wehnelt or electroltyic interrupter. It consists of a beaker containing sulphuric acid and water, in which there is placed a lead plate, *a*, as cathode, and a glass tube, *c*, into one end of which a platinum wire has been sealed, as anode. Mercury may be poured into the tube around the platinum wire in order to keep it from overheating. When this device is put in the circuit of the primary current of an induction coil, instead of the magnetic break above described, very rapid interruptions of the current take place. With this form of interrupter the condenser need not be used.

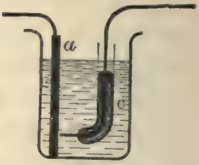


Fig. 354

400. Effects of the Inductive Discharge. — The mechanical and heating effects of the inductive discharge are practically similar to those obtained from the discharge of the Holtz machine, and the experiments made with that machine may be repeated and added to, using the induction coil instead. The physiological effects are peculiar. They should be obtained by taking hold of the terminals of the secondary, in a *small* coil. The effect from a large coil is often painful.

401. Luminous Effects. — We have considered the high E.M.F. required to send a spark across a short air gap. If, however, the terminals are separated by air at a reduced pressure, the spark loses its intense brilliancy, and may be increased in length. This condition is secured by sealing platinum wires into the opposite ends of a glass tube from which nearly all the air has been removed. When this tube is attached to the secondary terminals of a Ruhmkorff coil, in a dark room, and the current is turned on, the tube will be filled with a band of violet light. Platinum wire is selected for sealing into the glass, because its coefficient of expansion is nearly the same as that of the glass.

FIG. 355

402. Geissler Tubes are glass tubes of various forms, supplied with platinum terminals and filled with different gases at different pressures. When the current from the secondary of an induction coil is sent through them, it gives rise to many brilliant luminous effects. These coils are shown in Fig. 356. Tubes of the form shown in Fig. 357 are used in the spectrum analysis of gases.

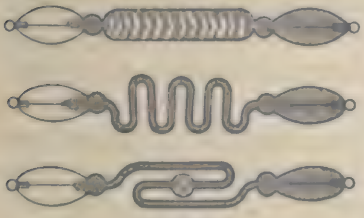


FIG. 356

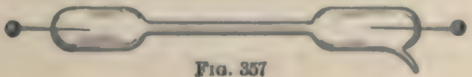


FIG. 357

403. Crookes Tubes. — Professor William Crookes has made a study of the phenomena of electric discharges in high vacuum tubes. By a high vacuum is meant one in which the gaseous pressure is not more than one-millionth of that of the atmosphere. Figure 358 shows the form of tube with which he studied the difference between the phenomena when high and low vacua are used. If the vacuum is low, the discharge shows a curved band of light from the cup-shaped platinum cathode to whichever wire is made the + terminal. If, however, the vacuum is high, the discharge passes from the cathode directly across the globe to the opposite wall, which glows with a yellowish green fluorescence.

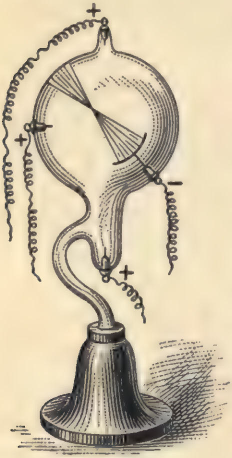


FIG. 358

404. The Röntgen Rays. — In December, 1895, Professor Röntgen of Würzburg announced a most important discovery. This is that certain luminous tubes, when the secondary current from an induction coil is sent through them, have the property of sending off invisible rays that are capable of making fluorescent substances glow and of affecting the photographic plate. They have, moreover, the property of passing through many opaque substances, as rays of light pass through transparent substances. These rays proceed from that part of the surface of the tube upon which the cathode rays strike, and were called by Professor Röntgen *the X rays.*

The announcement of this discovery aroused the greatest interest, both scientific and popular, an interest that received a great impetus from the fact that, while the rays pass through flesh with very little difficulty, the bones offer a much greater obstruction. This makes it possible to locate the position of the bones, and is of very great help to the surgeon in setting a broken bone or in locating the presence of a foreign body — a bullet, for instance. Figure 359 represents a photograph taken by means of the Röntgen rays. The usual method of taking such photographs is as follows: The photographic plate is inclosed in a plateholder, the object to be photographed is placed upon the cover of the holder, and the Röntgen rays are directed upon it, the source of the rays being only a few inches away.

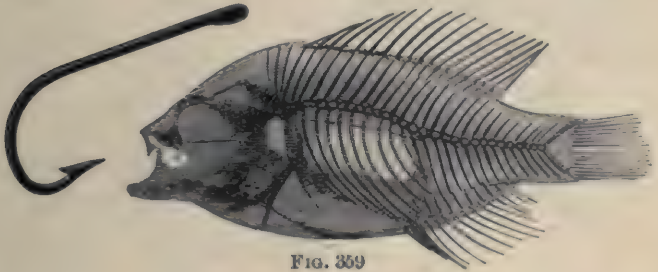


FIG. 359

Several forms of Crookes tubes are capable of giving off the Röntgen rays, the one shown in Fig. 358 being an effective form. The most recent forms are what are called focus tubes, in which the cathode rays are brought to a focus on a platinum plate turned at such an angle that the rays will be sent out radially through the glass.

It is found that the vacuum in a Crookes tube increases with use, so that the current will no longer pass, and the tube is useless until the vacuum is reduced. To regulate the vacuum automatically, the tube shown in Fig. 360 has been devised. Besides the main tube there is a small side tube attached as shown. After the vacuum has become so high that the current will no longer pass through the large tube, a spark jumps across the gap between *W* and *A* and passes through the smaller tube, in which the cathode rays sent off from *D′* strike upon the bulb *B*. This bulb, which is connected with the main tube, contains a chemical that has a great affinity for moisture. The rays from *D′* heat the bulb *B* and the moisture is driven into the larger tube, reducing the vacuum, and keeping it practically constant.

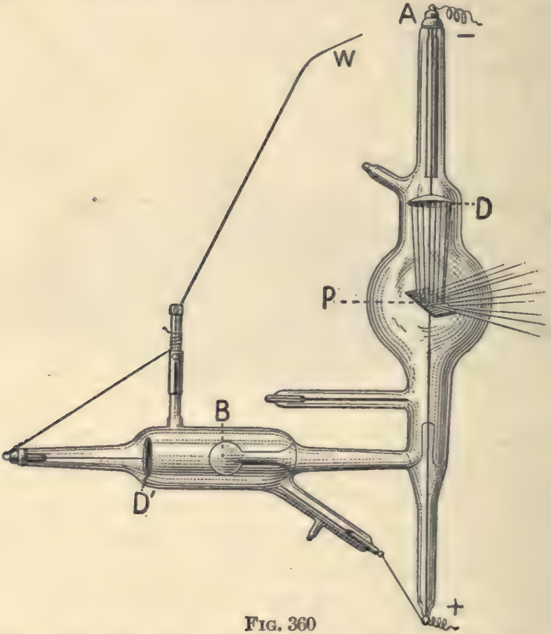


Fig. 360

According to two theories proposed, the Röntgen ray waves are longitudinal vibrations of the ether; or they are transverse vibrations shorter than those which produce light — vibrations caused by a molecular bombardment of the + terminal. Many phenomena favor the second theory. The rays can be produced by attaching the tube to the terminals of the Holtz machine, as well as by attaching it to the secondary terminals of the Ruhmkorff coil.

405. The Fluoroscope, a form of fluorescent screen shown in Fig. 361, was devised by Edison in order that he might study the effect of the Röntgen rays without the use of photographic plates. It consists essentially of a screen covered with crystals of calcium tungstate and fixed to a boxlike support with opaque sides which, opposite the screen, fit so closely around the eyes that they cut off all outside light. By means of the fluoroscope one may examine, for instance, his own hand by putting it before the screen and looking through the screen toward a tube that is giving off Röntgen rays; the bones of the hand can then be seen outlined upon the fluorescent calcium tungstate.

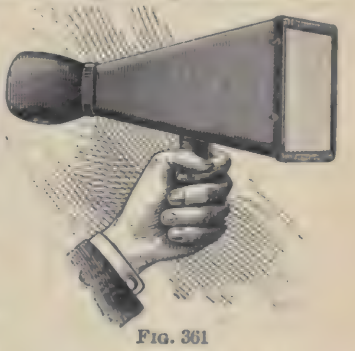


FIG. 361

406. The Dynamo is a machine by which mechanical energy is used to produce an electric current by moving a series of conductors in such a way that they cut magnetic lines of force.

407. The Ideal Simple Dynamo. — Under ideal conditions for a simple dynamo, the conductors would move in a uniform magnetic field. The nearest approach to this condition is obtained by using permanent magnets for the fields *N* and *S*, Fig. 362; a machine of this kind is called a *magneto*. By applying the laws for induced currents we may determine the direction of the current produced by the dynamo. Suppose the single coil in Fig. 362 is turned from its vertical position, clockwise; the first movement will cause the conductor to move in a direction almost parallel to the lines of force, so that there will at first be very little cutting of the lines, and hence very little induced current. As the coil moves from its vertical position to a horizontal one, the rate at which the lines of force are cut increases until the coil reaches the horizontal position, when the rate is a maximum. As the coil is turned still farther, the rate at which the lines of force are cut decreases, until, when it has passed through 180°, the induction becomes zero. The direction of the induced current in the upper branch will be from the left toward the right (with reference to a person looking from *N* to *S*), as in Fig. 347. The induction in the lower part of the loop, as it rises, will be from right to left, and thus the two currents will join and flow in the same direction. Every time the coil passes through the vertical position, the direction of the current induced in it changes, so that there will be two alternations of current for every revolution.

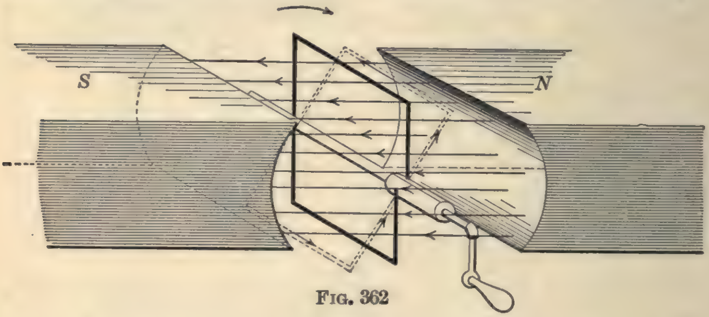


FIG. 362

408. The Commutator. — In order that the current taken from the coils of a dynamo may be in one direction, the ends of the coils are connected with copper terminals that revolve with the shaft, while the currents are taken off by brushes. A two-part commutator, suitable for a single coil, is shown in Fig. 363. A study of this figure will show that the brushes can be placed in such positions that the change from one commutator bar to the other shall take place just as the direction of the current in the coil changes; and for this reason the current in the external circuit will always be in one direction.

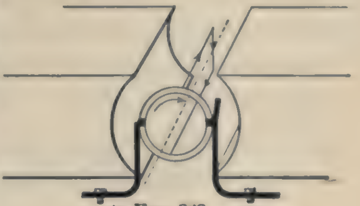


FIG. 363

409. — The Armature. — That part of the dynamo in which the current is induced is called the *armature*. This is generally a rotating part, but in some machines it is stationary. Modern armatures are mostly of two types: the ring armature and the drum armature.

410. The Ring Armature consists of a number of coils of insulated wire wound upon a core which has the form of a ring. Figure 364 shows a simple form of ring armature. By applying the rule for direction of induction, we may determine the brush with which the + terminal is connected. Since one half the whole number of coils is in series between the brushes on each side, it is

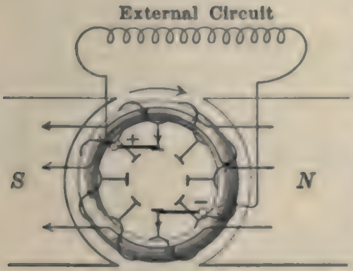


FIG. 364

evident that the E.M.F. will be the sum of the E.M.F.'s induced in all the coils on either side, and that the resistance of the armature will be one fourth of the resistance of all the wire upon it. This form of armature is adapted to machines designed for high voltage, such as those used in arc lighting.

411. The Drum Armature consists of conductors wound lengthwise upon a cylinder of iron. The ends of the coil are connected with the armature on opposite sides. This form is used for lower E.M.F. than the ring armature. If a large current is to be taken from the machine, the conductors are made of copper bars or rods. Figure 365 shows the general form of the drum armature.

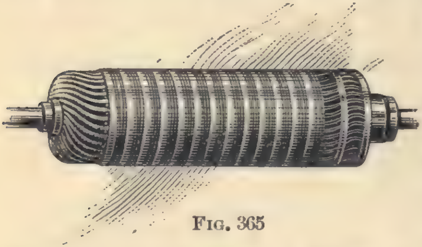


FIG. 365

412. The Field Magnet. — There are several methods employed to produce the magnetic field, and these determine the classes to which dynamos belong.

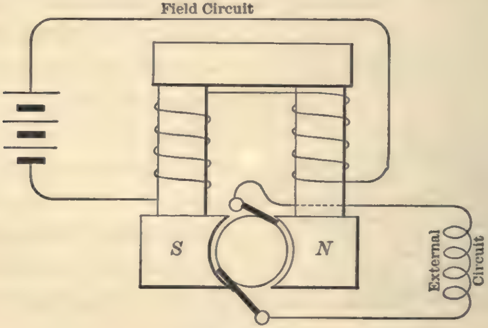


FIG. 366

413. The Separately Excited Dynamo has a magnetic field produced by a current from some outside source of electricity, such as a battery or another dynamo (Fig. 366). This current may be regulated so that it shall be constant, and the magnetic field is thus kept from changing as the current in the outside circuit of the dynamo changes.

414. The Series Dynamo has a field produced by a coil of large wire, wound on the field magnets, that is in series with the external circuit. Figure 367 shows how the connection is made from the upper brush around the field magnets, then through the external circuit, and back to the lower brush. If the external circuit is broken, the magnetization of the field falls practically to zero. If the current in the external circuit increases the E.M.F. rises.

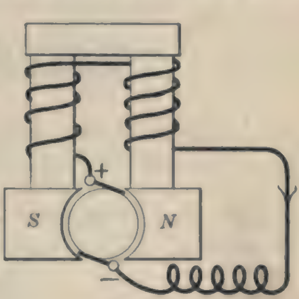


FIG. 367

415. The Shunt Dynamo.—In the very useful form called the *shunt dynamo*, the wire wound on the field magnets is a long coil of small wire coupled to both brushes as a shunt to the external circuit (Fig. 368). If the external circuit is broken, more current passes through the shunt and the magnetism of the field is increased, causing the E.M.F. of the machine to rise to its maximum. If the external current increases the E.M.F. falls.

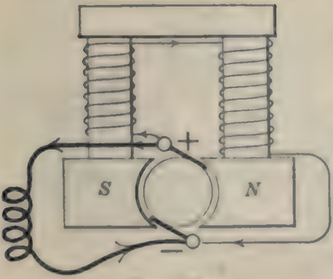


FIG. 368

416. The Compound Dynamo. — Since the E.M.F. of the series dynamo increases with the current in the external circuit, while the E.M.F. of the shunt dynamo diminishes as the current in the external circuit increases, it is possible to wind both a series and a shunt coil on the same field magnets, and so to proportion them as to keep the E.M.F. practically constant at all loads. This *compound winding* is shown in Fig. 369. The compound dynamo is the machine usually used for incandescent lighting.

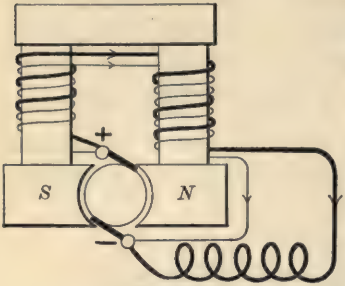


Fig. 369

417. The Alternator. — If the coils of a dynamo are coupled to copper rings instead of to the bars of a com-

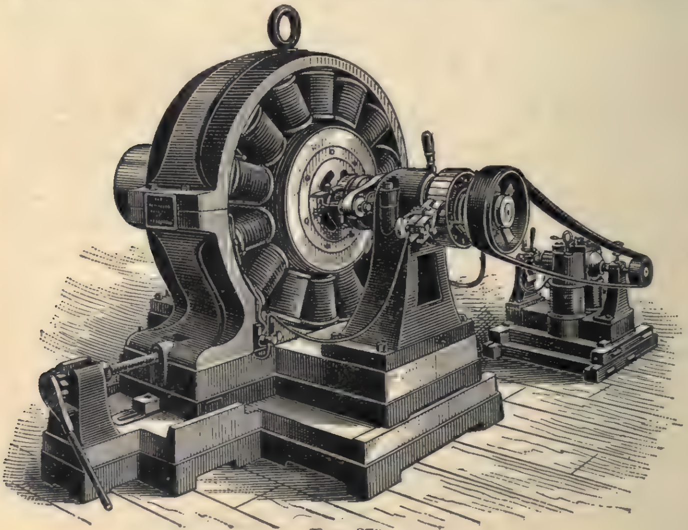


Fig. 370

mutator, the current will be an alternating one, changing its direction twice for every rotation of each coil. By using as many pole pieces to the field as there are coils, and by coupling the coils properly, the currents in all the coils are put in series, giving an alternating current of high E.M.F. The field magnets of an alternator (Fig. 370) are usually magnetized by a current from a small direct-current machine, called an *exciter*.

PRACTICAL QUESTIONS AND PROBLEMS

1. What is an induced current? How is it produced? Can it be produced without the presence of magnetism? Can you prove your answer?

2. Explain the induction of a current in a coil by the making and breaking of a current in an adjacent coil.

3. What is self-induction? What effect upon self-induction is produced by winding a coil as the coil of a resistance box is wound?

4. What would be the effect of rotating the coil in Fig. 363 in the opposite direction?

5. Draw a figure of the magnetic circuit of a dynamo with a ring armature and show what part of the wire cuts the lines of force.

6. Shunt-wound dynamos have some form of resistance box or rheostat in series with the shunt winding to regulate the field. Make a drawing to show its position. Explain its action.

7. What is the function of the iron core of the field magnet?

8. Make a drawing of a four-pole dynamo, showing the magnetic circuit. How will you couple the brushes so that the voltage of the machine will be the same as either pair of brushes?

9. How will it affect the E.M.F. of a dynamo to increase its speed? Why? To diminish the number of conductors on the armature? Why?

10. State the requirements of voltage and current for a dynamo to give current for (*a*) incandescent lighting; (*b*) arc lighting; (*c*) electroplating; (*d*) electric heating.

LABORATORY WORK

1. Make a long bar magnet by winding a coil of wire around a round steel rod, sending a heavy current through it, and striking the rod a few times while the current is flowing. Wind an exploring coil

that will slip over the rod, using a great many turns of No. 30 wire. Make two movable stops that will fit tight to the rod, by boring holes in two blocks. Place one in the middle of the bar and the other four inches away, with the exploring coil between them. Fasten the second block and the coil together by means of a light rubber band. Bring the coil slowly to the first block and then let go. The rubber band will quickly snap it across the space and the galvanometer will give a slight throw. Move both blocks a half inch toward the end and repeat. Go over the whole length of the bar in this way and make a curve showing the relation between the distance of the coil from the middle of the magnet, at each experiment, and the corresponding throw of the galvanometer.

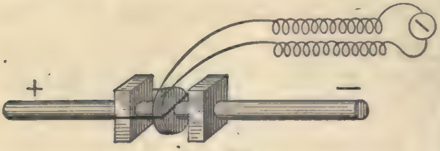


FIG. 371

2. Wind a coil of No. 16 wire 3 inches long, so that it will slip over the rod used in No. 1. Connect the ends of this coil with a battery and fix the coil in the middle of the bar magnet. Place the exploring coil of No. 1 over the magnet. Notice the throw of the galvanometer when the circuit is broken in the primary coil. Use an iron rod in place of the magnet and repeat. Explain the change in the throw of the galvanometer.

3. Couple a telephone receiver to the exploring coil and repeat the experiment. Does the telephone verify the results obtained by the galvanometer?

4. Slip the two coils on the opposite ends of an iron rod a foot long. Couple the telephone to the exploring coil. Couple the primary coil to a battery with a switch in the circuit. Find the position the coils must have to get the maximum inductive effect. Explain.

5. While the use of a commutator on an armature makes the current pass always in one direction, it does not secure an entirely uniform current. There is still some fluctuation, which can be studied as follows: Use the coils and telephone receiver of No. 4, coupling the large coil to a direct-current dynamo, and putting considerable resistance in series with it to reduce the current. Couple the telephone to the small coil. Hold it to the ear and send the dynamo current through the large coil. The hum heard will determine, by its pitch, the rapidity of the fluctuations; and by its intensity, the amount of the fluctuation.

VI. THE COMMERCIAL APPLICATION OF ELECTRICITY

418. The Electric Bell. — The common electric bell is an application of the electro-magnet. Figure 372 shows the connections of a bell and its circuit. When the button at *B* is pressed, the current enters by the + binding post; passes around the electro-magnet; then to the post *P*, through which runs a pin that makes contact with the armature of the magnet by means of a light spring; then along the spring *S* to the − binding post. As soon as the current is made, the armature of the electro-magnet is attracted and the current is broken at *P*. When this happens the magnet no longer attracts the armature, and the spring *S* carries it back against the post *P*, again making the circuit. This causes the bell to ring automatically as long as the button is pushed. When two or more bells are to be rung from a single push button, they should be coupled in parallel, as they will not ring well in series unless they strike at exactly the same rate. Why?

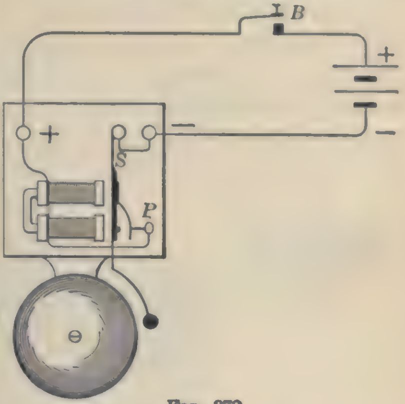


FIG. 373

419. The Electric Telegraph. — It is evident that the electric bell can be used for signaling at a long distance. The telegraph, which is used especially for this purpose, depends upon the same principle: that of the electro-magnet. The principal parts of the telegraph are the main battery and line, the relay, the local battery and circuit, the sounder, and the key.

420. The Key (Fig. 373) is simply a circuit breaker put in the main line. It is generally screwed to a table by two screws which connect it with the main line. One of these is insulated from the base of the key and terminates in a platinum point. The other is connected with the lever of the key, and the current is sent every time the lever is pressed down so as to touch the platinum point.

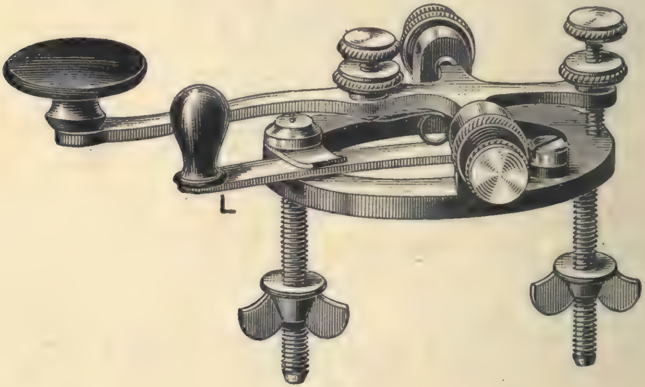


FIG. 373

When the key is not in use for sending messages, the lever *L* is pushed in, making direct contact so that messages can be received.

421. The Main Battery consists either of a group of gravity cells or of a dynamo. The latter is coming into use in long lines, since it is more convenient and takes less room than the number of cells necessary. There is usually a main battery at each end of the line.

422. The Line generally consists of iron wire supported by glass insulators attached to the line poles. At one terminal station the + pole of the battery is connected with the line and the − pole is connected with the earth or is "grounded," while at the other terminal station the − pole is connected with the line and the + is grounded. At intermediate stations the line is simply coupled to the terminals of the relay.

423. The Relay (Fig. 374) is an electro-magnet of high resistance in series with the main line. Its function is to make and break contact in the local circuit which controls the sounder. The way in which this is done will be seen by referring to Fig. 376. The relay is wound with a great many turns of fine wire so that the small main current may be able to magnetize it.

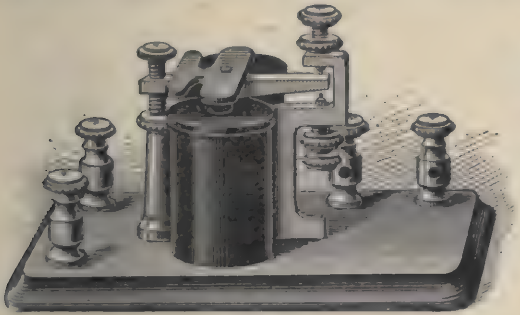


FIG. 374

424. The Sounder (Fig. 375) is an electro-magnet, in the local circuit, from which the message is read. This

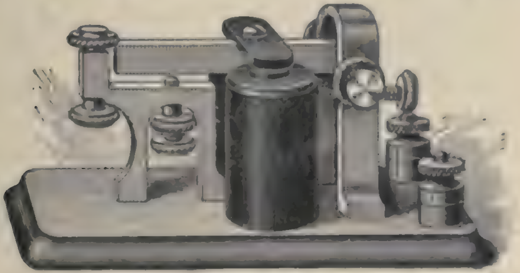


FIG. 375

sounder is wound with fewer turns of wire of a larger size than that used in the relay. Since the local battery has only the resistance of the sounder to overcome, the current is large enough to make the electro-magnet attract its armature with fewer turns.

425. Connection and Operation of the Line. — Let Fig. 376 represent, diagrammatically, a line having Philadelphia and New York for its terminal stations and Trenton for an intermediate station. The connections are arranged for sending a message from New York to Philadelphia. The switch *S* at Philadelphia is closed, that at New York is open. When the operator at New York presses his key the connection is made along the line, and at Philadelphia the current goes through the relay and then through the battery to the earth. Its action upon the relay is to magnetize it and cause the armature *A* to be attracted. As soon as the armature moves toward the magnet it comes in contact with the pin *P*, and as this is coupled to one side of the local battery and the armature to the other side through

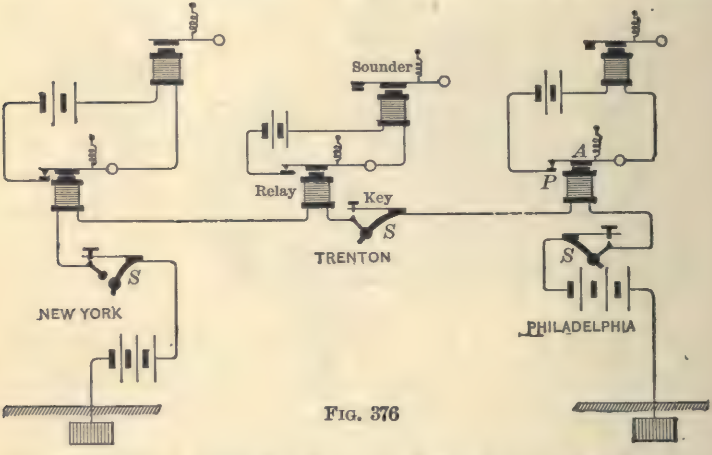


Fig. 376

the sounder, the local circuit is made and the sounder attracts its armature. As soon as the sender at New York releases his key the circuit is broken, *A* is pulled back to its normal position by the spring, the local circuit is broken, and the condition is just as it was before the signal was sent.

The message sent to Philadelphia may also be read at Trenton; for the current has the same effect on any intermediate relays that it has on the Philadelphia relay. If the message had been intended for Trenton, the New York operator would have first sent the Trenton "call" until the Trenton operator had responded.

426. Duplex Telegraphy is the name given to a method employed for using a single wire for sending messages both ways at the same time. The instruments at each end are connected in such a way that the sounder responds only to the key at the other end of the line. By the use of other devices two or more messages may also be sent in the same direction at the same time over one wire.

427. The Telegraphic Alphabet. — Telegraphic messages are sent by what is known as the Morse alphabet. This consists of a series of dots and dashes with intervals between the letters and longer intervals between the words.

In the first instruments there was used a special receiver that traced the dots and dashes upon a strip of paper. The universal custom now is to read by sound.

The Morse Alphabet

A - —
B — - - -
C - - -
D — - -
E -
F - — -
G — — -
H - - - -
I - -
J — - — -
K — - —
L ——
M — —
N — -
O - -
P - - - - -
Q - - — -
R - - -
S - - -
T —
U - - —
V - - - —
W - — —
X - — - -
Y - - - -
Z - - - -

428. Wireless Telegraphy. — The system of wireless telegraphy, that has been rendered highly successful by Marconi, depends upon the change made in the resistance of a metallic powder by an electrical oscillation sent out from the secondary spark of a Ruhmkorff coil. A diagram of the instrument used in a sending station is shown in Fig. 377. The instrument consists chiefly of a Ruhmkorff coil in which the make and break in the primary circuit is controlled by a telegraph key. The sparks that set up the required oscillations pass between two brass balls on the terminals of the secondary coil. One terminal of the coil is also connected with a vertical wire that is fastened at the top to a metallic sheet, and sometimes the other terminal of the coil is connected by a wire with the ground.

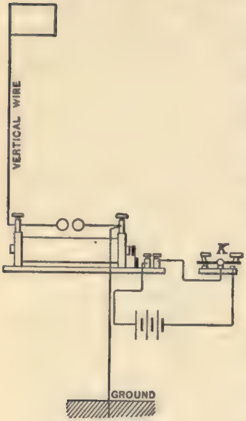


FIG. 377

A diagram of the receiving instrument is shown in Fig. 378. This has a battery of two or three cells coupled in series to a glass tube containing the powder, such as brass filings, upon which the electric oscillations act. This part of the apparatus, *C*, is called a coherer. An ordinary telegraphic relay is also coupled in series. The armature of the relay makes and breaks the local circuit, which consists of a battery, sounder, and an electro-magnet with a vibrating armature, *D*, called a decoherer. One side of the coherer

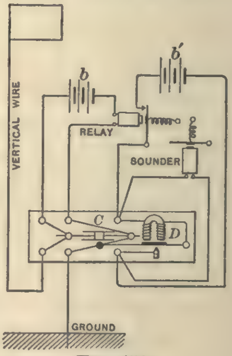


FIG. 378

is connected with a vertical wire, and the other with the ground, as in the secondary of the sending instrument.

The operation of the instrument is as follows: When the key *K* is closed in the sending instrument, sparks pass between the knobs of the secondary coil. These set up electrical oscillations that pass through the air and strike the coherer. On meeting the coherer, these waves change its resistance from an amount that makes it practically a nonconductor to a comparatively few ohms; and the current from the battery *b* passes through it. This closes the local circuit, and a current is sent by the battery *b′* through the sounder, giving the desired signal, and at the same time through the decoherer, the armature of which strikes against the coherer, bringing it again to its normal condition of practically infinite resistance, and thus stopping the current in the local circuit.

The distance through which signals can be sent and received depends upon the sensitiveness of the instruments and upon the height of the vertical wire. Experiments have shown that the distance varies directly as the square of the height. Messages were sent across the English Channel, a distance of thirty-two miles, by using a vertical wire one hundred and fifty feet high.

429. The Telephone. — Experiment 208. — Wind a coil of No. 30 insulated copper wire on a spool that will slip over the end of a quarter-inch steel rod 6 in. long. Magnetize the rod slightly. Couple one terminal of the coil to a battery and the other to a tin plate 2 in. square. Cover this plate a half inch deep with a layer of powdered charcoal. Couple a similar plate to the other pole of the battery, and lay it upon the charcoal.

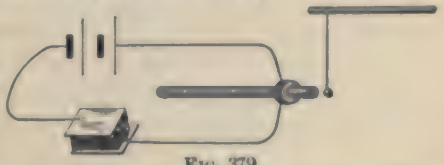


FIG. 379

Cut out a small disk of thin iron (ferrotype plate is best) and suspend it in front of the magnet. Press the charcoal between the plates and observe the movements of the disk. Reverse the battery connections and repeat. Explain.

The telephone is an instrument used for the purpose of transmitting speech to a distance. The *receiver* of the Bell telephone, which can also be used as a transmitter, is shown in section in Fig. 380. *M* is a bar magnet, over the end of which a coil of fine wire is fixed. In front of this end of the magnet a thin disk of iron is fixed by its edge. Wires leading from the coil through the handle are fastened to binding posts in the end. When a current of electricity passes through the coil it will change the number of lines of force going out from the end of the magnet, and either increase or decrease the attraction the magnet has for the disk. If at the transmitting end of the line a person speaks into a similar instrument, the rarefactions and condensations of air produced by the voice will produce vibrations of the disk, the distance of which from the end of the magnet will be changed, inducing currents in the coil. These currents coming to the receiver end, and passing about its coil, will set up similar vibrations in its iron disk, which will set up rarefactions and condensations in the air and thus reproduce the original sounds.

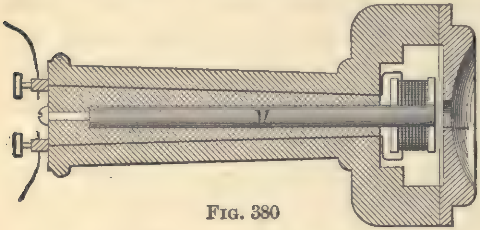


FIG. 380

430. The Microphone. — EXPERIMENT 209. — Couple one binding post of a telephone receiver to a battery and the other to an electric light carbon. Connect a second carbon with the other terminal of the battery. Lay one carbon upon the table and rest the other across it. Hold the telephone to the ear and notice the sounds that result from moving the carbons over each other. These sounds mean changes in the current, and the only change in the circuit is in the resistance of the carbon contacts.

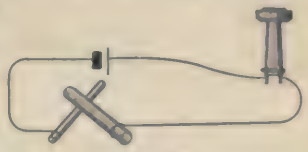


FIG. 381

The *microphone* is an instrument used for the purpose of increasing the intensity of slight sounds. The principle upon which it is based, is that of the change that takes place in an electric current with the change in the resistance of the circuit. A common form of the instrument is shown in Fig. 382. It has a sounding base to which an upright board is attached. Through this upright project two carbon pencils, with a hole drilled in one side of each pencil near the end, so as to support a smaller carbon pencil. These carbon rods are coupled in series with a cell and a telephone receiver. If any slight noise is made near this

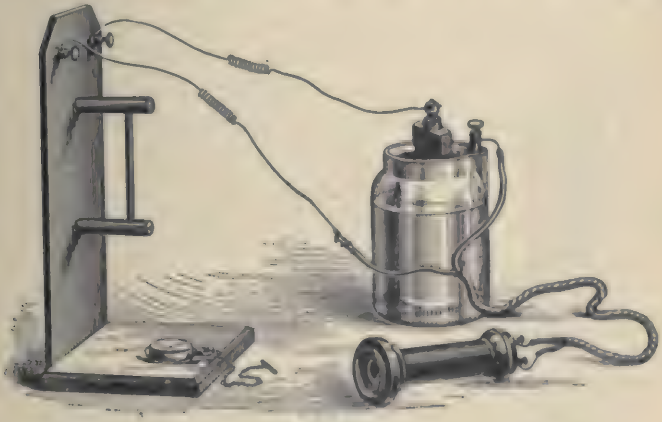


FIG. 382

microphone the sound waves set up in the board will affect the carbon contacts in such a way that the sounds will be heard in the telephone with much greater intensity.

431. The Microphone Transmitter. — The transmitting instrument in general use is a form of microphone called the *Blake transmitter*. The use of this transmitter requires a battery in the main line. Figure 383 shows the arrangement and connections of this instrument in a telephone station. The transmitter consists of a mouthpiece back of which is a soft iron disk. In contact with this is a platinum point which is carried by a spring *s*. A second spring *s′*, from which the first is insulated, carries a small block of carbon that rests lightly against the platinum. This carbon block is coupled to one side of a cell and the spring *s* to the other side, the primary of an induction coil *C* being in the circuit. The secondary of the coil is connected on one side with the main line, and on the other through the receiver with the ground. When, on account of the air vibrations produced by the voice, the disk vibrates, it changes the pressure between the platinum and the carbon. This varies the current sent through the primary and induces in the secondary a current, which is carried by the line to the second, receiving instrument.

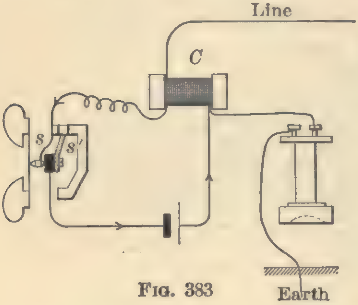


FIG. 383

Much more satisfactory results are obtained by using a second wire for a return instead of grounding the instrument. The use of the second wire prevents the effect of induction by other currents near the line, such as currents for lighting and trolley currents; for the same induction is set up in both wires and its effects oppose each other. Also, greater distinctness is secured. The double circuit in the long distance telephone between New York and Chicago is very satisfactory.

432. Electric Lighting. — Another very important use to which the electric current has been put is that of furnishing light. The lighting is done by the use of two different kinds of lamps: the arc and the incandescent. There are also two different methods of producing the current for either lamp: by the use of direct-current dynamo, and by the use of the alternator.

433. Arc Lighting. — EXPERIMENT 210. — Attach two copper wires to the terminals of a battery and wind the end of one of these around a file. Rub the end of the other wire along the face of the file, and notice the sparks that are given off every time the circuit is broken in passing from one projection of the file to another.

The sparks that are given off in this experiment are small arcs in which a part of the copper wire is burned. The commercial arc light is produced by sending a current of electricity from one carbon rod to another across a short air gap. In order to maintain the ordinary arc a difference of potential of from 45 to 50 volts is required, and this sends through the arc a current of from 9 to 10 amperes.

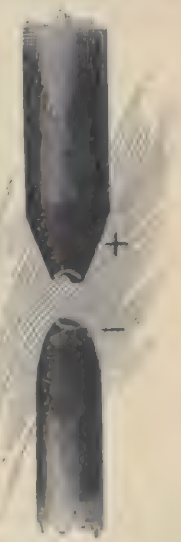


FIG. 384

Figure 384 gives a view of the carbons. The upper or + carbon is very much hotter than the − carbon, and as the current passes, the carbon becomes incandescent and some of it passes across the space between, forming a conductor for the current. This gives to the + carbon a cuplike shape in the middle, and this cup is the seat of the most intense artificial light and heat known.

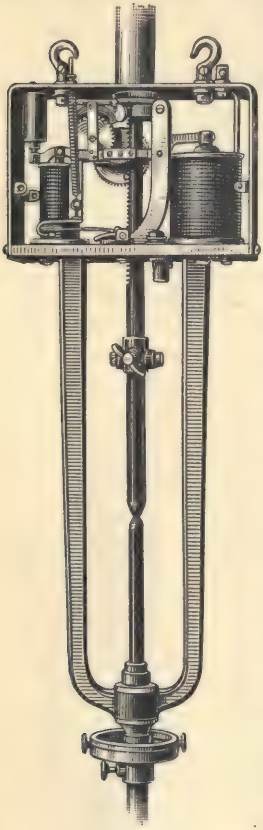


FIG. 385

434. The Mechanism of the Arc Lamp (Fig. 385). — As the carbon wears away between the terminals of the lamp, the resistance of the arc increases with its increasing length, and not enough current flows to keep the arc bright. In order to keep the proper current flowing, the arc must be of as nearly a constant length as possible. This result is secured by means of a pair of electro-magnets, of which one is in series with the current, and the other is a shunt across the arc. The lengthening of the arc causes more current to go through the shunt circuit. This shunt circuit is so arranged that when a certain current goes through it, the carbons are brought nearer together. This shortens the arc, reduces the current in the shunt coil, and increases that in the series coil. The series coil is so arranged as to draw the points farther apart, if they have approached too near and the current is too great. In a properly designed lamp these actions are very slight, giving a steady and not a flickering light.

Arc lamps are generally connected in series, the number in any circuit determining the potential difference needed at the terminals of the dynamo. If there are to be 26 lamps on a certain circuit, each requiring 45 volts, the dynamo must furnish 1170 volts for the lamps, plus the amount necessary to send the current through the leading wires.

Arc lamps called *inclosed arcs* are now made, having a small globe nearly air-tight surrounding the arc and a few inches of the carbon. In this form of lamp the carbon is burned much more slowly than in the open arc. Some of the inclosed arc lamps are intended for the 110-volt incandescent circuit, requiring a potential difference of 80 volts and a current of from 4 to 5 amperes.

435. Incandescent Lighting; Direct Current. — In the experiment in which a heavy current was sent through a small copper wire, it was found that the copper melted. If the same experiment is made with a platinum wire, the wire will not melt, but will become intensely hot, and glow with a very bright light. The incandescent lamp (Fig. 386), consists of a glass bulb, into the base of which there are sealed two platinum wires, which carry a loop of carbon filament. The air is exhausted from the bulb before it is sealed. When the proper current is sent through the carbon filament it becomes incandescent, that is, gives off light, but does not burn, as there is no air in the bulb. After a lamp has been used for some time, part of the carbon becomes deposited on the inside of the bulb, and absorbs a great deal of the light sent out by the filament. When this has happened the best economy is to destroy the lamp and replace it by a new one.

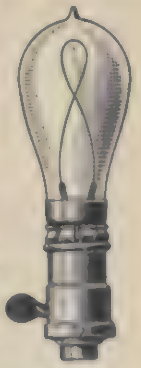


FIG. 386

436. The Incandescent Circuit. — Incandescent lamps are coupled in parallel across the mains, or leading wires from the dynamo. Fig. 387 illustrates a simple incandescent circuit. The dynamo is first run until the voltage at its terminals is 110 volts, and then any lamp or group of lamps in the circuit can be turned on. The hot resistance of a 110-volt lamp is about 220 ohms; consequently each lamp requires a current of half an ampere. The parallel resistance of 2, 3, or n lamps being only $\frac{1}{2}$, $\frac{1}{3}$, or $\frac{1}{n}$th part of the resistance of a single lamp, the same dynamo that will light one lamp, will light a number. If it were possible to build a dynamo without any internal resistance, the number of lamps that could be lighted would be very large. As this cannot be done, the number is limited by the internal resistance and reactions. Several groups of wires are usually run from one dynamo. A group can be run from the mains at any point by coupling submains to them, that is, by attaching to each wire a branch wire large enough to carry the current for its group. Each arch in the line (Fig. 388) where one conductor crosses another indicates that it does so without touching it, or that the two are insulated from each other.

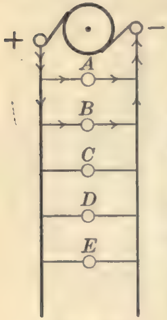


Fig. 387

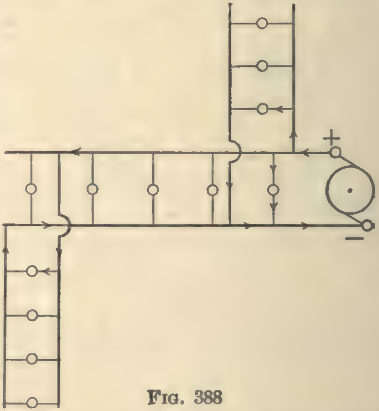


Fig. 388

437. The Three-wire System.—In order to reduce the expense of distribution, Edison devised the three-wire system, in which two similar dynamos are coupled in series (Fig. 389). The main feeding wires are attached, one to the positive of the first dynamo, and the other to the negative of the second. A third wire is attached to the negative of the first and to the positive of the second dynamo. If there are an equal number of lamps burning on each side of the middle wire, it will carry no current, but if there are 50 lamps on one side and 55 on the other, for instance, it will carry the current for 5 lamps. The middle or *neutral* wire is often grounded.

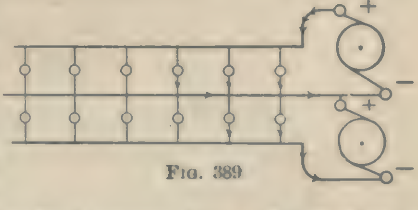


Fig. 389

Incandescent lamps are rarely run in series on direct current circuits. In trolley cars, however, which are fed with a 500-volt circuit, 5 lamps of 100 volts each (or 10 of 50 volts each) are usually put in series.

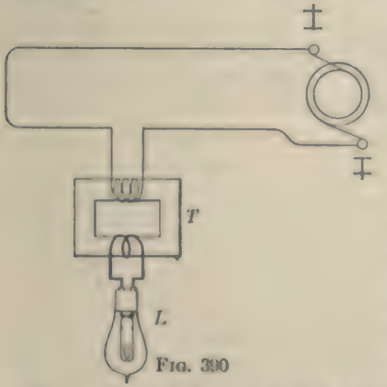


Fig. 390

438. Incandescent Lighting; Alternating Current.—Since alternating dynamos are built to give high voltage, some method for changing this voltage to that which can be used in a lamp is necessary. A *transformer* is used for this purpose; it is virtually a reversed Ruhmkorff coil,—reversed because the work to be done is to change a high potential current into one of a low potential. The principle of the transformer is shown in Fig. 390. The current from the dynamo flows through a long coil of fine wire which has an iron core to increase the magnetic field. By the side of this coil and surrounding the same core is a second coil, shorter and of larger wire. To the terminals of this coil the lamp or lamps to be lighted are attached. The size of the wire in these coils, as well as its length, is determined by the respective voltages of the dynamo and of the lamps to be used. In street lighting the lamps are sometimes coupled in series of 20, each having a shunt box. If any lamp goes out the coil in the shunt box carries the current, and produces the humming noise so frequently heard when a lamp has burned out.

439. The Electric Motor. — We have already learned that when a wire is carried across a magnetic field, cutting the lines of force, a current is generated in the wire. The converse of this is also true : if a current is sent through a wire that is in a magnetic field, the wire will be set in motion in a direction contrary to that which would have produced the current. A person can turn the armature of a 50 H.P. dynamo with one hand so long as there is no current generated and nothing to overcome but the friction ; but when the dynamo is being run at full speed and the current is being used, the work of an engine is needed to turn it ; the increase is the work that is required to force the conductors, while they are carrying a current, through these invisible magnetic lines of force.

It is this *magnetic drag* that becomes the power in an electric motor. In general any dynamo is reversible and can be used as a motor. Motors are in very general use for many purposes, and have made great changes in the methods of running machinery.

The E.M.F. of a dynamo or motor depends upon three things: speed, number of conductors, and number of lines of force cut. This relation may be expressed by the equation

$$E = \frac{nCN}{10^8}. \qquad (59)$$

In this formula n is the number of revolutions per second, C is the number of conductors on the armature, N is the number of lines of force cut by each conductor, and 10^8 is a constant necessary to reduce the product nCN to volts.

PRACTICAL QUESTIONS AND PROBLEMS

1. How can you prove that the direction in which a conductor cuts a line of force determines the direction of the induced current?

2. The ordinary Ruhmkorff coil is a "step-up transformer" and the transformer used on lighting circuits is a "step-down transformer." Explain these terms.

3. How do the Röntgen rays differ from light rays?

4. Draw a vertical cross section of a two-pole dynamo. Show (*a*) the field magnets, (*b*) the armature core, (*c*) the direction of the magnetic lines of force throughout the circuit.

5. Make a drawing of the two-pole dynamo with a ring winding. Prove the direction of the currents in the armature winding with a given position of the N and S poles of the field magnet, and direction of rotation of the armature. Locate the brushes and mark them + and −.

6. Draw a figure of a field winding that shall be a combination of a series and a separately excited coil.

7. Show by a figure how you would couple two electric bells so as to ring them both at the same time with one button.

8. What is the resistance of an arc lamp that requires a 9-ampere current and a potential difference of 45.8 volts to burn it properly?

9. Twenty-five of the lamps in No. 8 are to be run in series on a line that is 1 mi. long. The current is carried by a No. 10 copper wire (p. 453) and the internal resistance of the dynamo is 3.2 ohms. (*a*) What is the lamp resistance? (*b*) What is the entire resistance? (*c*) What is the potential difference at the terminals of the machine? (*d*) What part of the work given out by the machine is used in burning the lamps? (*e*) What part is lost in heating the line wire?

10. How many 50-volt lamps can a 2000-volt machine run in series, when one tenth of the voltage is lost in the leading wires?

11. An inclosed arc lamp requires 80 volts and 4.5 amperes to run it properly. (*a*) What is its resistance? (*b*) How much resistance must be added to it so that it shall carry the proper current when it is coupled to a 110-volt circuit?

12. Two 50-volt lamps that require 8 amperes each are put in series across the terminals of a 110-volt incandescent circuit. How much resistance must be put in series with them?

13. How many watts are used by an arc lamp that requires 45 volts and 9.5 amperes? How many such lamps can be run by a 30-H.P. engine, provided 90% of the energy of the engine is used in the lamps?

14. The hot resistance of a 100-volt, 16-candle-power lamp is 192 ohms. How many amperes are required to burn such a lamp? How many watts per lamp? How many watts per candle power?

15. If a 50-volt, 16-candle-power lamp requires as many watts as a 100-volt, 16-candle-power lamp, what current does it take? What is its resistance?

16. A dynamo, when run at a certain speed, showed a potential difference of 125 volts at its terminals, and sent a current of 24.5 amperes through a motor circuit. What was the resistance of the circuit?

17. An Edison dynamo gives a current of 320 amperes at a voltage of 105 volts. The resistance of the armature is .01 ohm. (*a*) What is the fall of potential through the armature? These are called *lost volts.* Suppose the current of this machine is used for electric heating. (*b*) Find the resistance in the heating circuit. (*c*) How much heat will be generated in 15 minutes?

18. A Kapp dynamo gives a current of 200 amperes at 105 volts, and the armature resistance is .025 ohm. (*a*) How many watts are used in the external circuit? (*b*) How many in the dynamo itself? (*c*) What is the effect of the watts used in the dynamo? (*d*) Is this a help or a hindrance to the work of the machine?

19. Four hundred incandescent lamps are burning on one side of an Edison three-wire system, and 426 on the other. The lamps being for 110 volts and .5 ampere, how much current is being carried by the neutral wire? How much by the positive leading wire, if the greater number of lamps are connected with the positive terminal? How much by the negative wire?

20. A 1000-volt alternating current of 2 amperes is sent through a transformer having an efficiency of 98%. How many 50-volt incandescent lamps can it light if each requires 1 ampere of current?

21. A two-pole dynamo that generates 110 volts has 80 conductors on the armature and runs at a speed of 750 revolutions per minute. How many lines of force are in the magnetic circuit?

LABORATORY WORK

1. To a board 30 inches long and 15 inches wide fasten two bells and two push buttons so connected with a battery that either button will ring both bells.

2. Set up a telegraphic line from one corner of the laboratory to the opposite one. Carry the lines along the walls and place the instruments on corner shelves in such positions that they will be permanent. Practice daily, for a few minutes, until the alphabet is learned and you can send a message.

3. Couple three Grenet or plunge cells in series. Couple a wire 20 feet long to one binding post and a short wire to the other. Touch the wires together and draw them apart. Notice the spark that passes. Wind the long wire upon a spool and repeat. How does the spark compare with the first spark? Explain.

4. If you have access to a 50-volt alternating circuit, wind a coil with half a pound of No. 18 insulated copper wire and fasten it to the base of a 50-volt lamp. Wind a similar coil and rest the lamp and its coil upon it. Explain the results. Introduce a soft iron core in both coils and repeat.

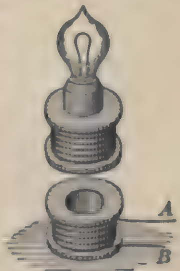


FIG. 391

5. Wind 2 lb. of No. 16 insulated wire on a wooden spool with an opening in it 2 inches in diameter. Bring the ends of the coil to binding posts on a base, to which fasten the coil. When an alternating current is sent through this coil, anything that is magnetized — a watch, for example — can be demagnetized by putting it in the middle of the coil and slowly pulling it out.

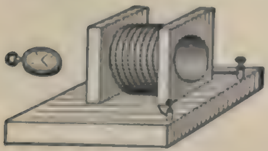


FIG. 392

6. Make a gallon of a solution of sodium carbonate having a specific gravity of 1.2. Add ½ lb. of borax. Place this in a battery jar. Couple a plate of sheet lead to the + pole of a dynamo that will give from 100 to 150 volts, and insert the lead in the solution. Couple an iron rod to the – pole, and place the end of it in the jar. This is called the "water-pail forge." Explain its action.

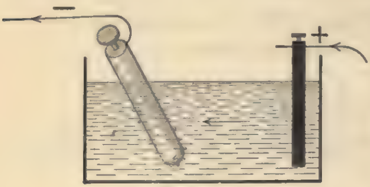


FIG. 393

7. Test the absorptive power of different substances for the Röntgen rays by the method described for making a picture with the photographic plate. Charge an insulated sphere with electricity, and then bring the X rays to strike upon it. After a short time test it for electricity.

CHAPTER X

LIGHT

I. NATURE AND INTENSITY OF LIGHT

440. Light is that physical action which, by its effect upon the retina, excites the sensation of vision. There are many reasons for supposing that this action is the vibration of the *luminiferous ether*.

441. **Nature of the Ether.** — Since our senses give us no conception of the ether, the only possible way to describe it is by the qualities that it must possess. It is elastic and rigid, is capable of displacement and of exerting pressure. It may be considered as a universal jelly, so thin as to pass readily through every known substance, and to permit the densest substance to pass through it as a sieve passes through the air; a jelly so thin that it has no appreciable weight. It transmits in all directions the periodic changes in its electro-magnetic condition that constitute the light vibrations set up by a luminous body.

442. **Luminous Bodies** are those that emit light. The term is usually applied to those bodies only that are *self-luminous*. *Transparent bodies* are those that permit light to pass through them in such a way that objects are distinctly visible through them. When the light comes through a body as diffused light, and objects cannot be distinctly seen through it, the body is called *translucent*. If the body does not permit light to pass through at all, it is called an *opaque* body.

The classification of bodies as opaque and transparent is not very accurate, for thick layers of transparent bodies absorb a great deal of light, while thin layers of opaque substances are sometimes transparent.

EXPERIMENT 211. — Place a sheet of gold leaf between two thin glass plates and look through it at a window. You will find not only that it is transparent, but also that its color by transmitted light is green.

443. The Propagation of Light. — A luminous *ray* is a single line of light propagated from a luminous point. A group of rays from the same source is a *pencil* of rays. If these rays are parallel, they constitute a *beam of light*. If they diverge from a point, they form a *diverging* pencil. If they meet at a point, they form a *converging* pencil.

As long as the medium through which light moves is homogeneous, the direction of propagation is in straight lines. This propagation of light in straight lines is seen when the sun shines through a shutter into a darkened room. In this case the floating dust marks the path of the rays. A beam of light passing into a space which is free from all floating dust cannot be seen unless the eye is so placed as to look directly toward the source of light. Air can be made optically pure by passing it through a red-hot tube and then through a plug of cotton.

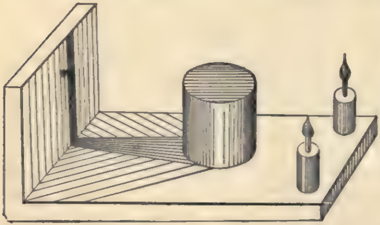


FIG. 394

EXPERIMENT 212. — Select a board about 2 ft. long and 8 in. wide, and set up in the middle of it a wooden cylinder 3 in. in diameter and 4 in. high. Near one end of the board set up two candles 4 in. apart, and observe the shadow cast by the cylinder upon the board.

444. Umbra and Penumbra. — In Experiment 212 the dark part where the shadows overlap is the *umbra*, and the part which is lighted by only one candle is the *penumbra*. When the source of light is so small as to be considered a single point, the shadow is all umbra. If the source of the light is larger, the umbra is partly or completely surrounded by a penumbra. Figure 395 illustrates the case in which the light comes from a luminous ball and the opaque body is a larger ball. If *L* is the luminous and *B* the opaque ball, a screen *S* will show the existence of a circular umbra or shadow whose limits can be determined by moving a straight line around both balls and tangent to both of them on the same side, as *LB*. There will be a penumbra, however, entirely around the umbra; this will extend to the limits of a circle marked by a line tangent to both balls, but always on opposite sides of them, as *CB*. At the edge of the umbra the penumbra will be nearly as dark as the umbra, and it will gradually grow lighter and lighter toward the outer edge. If one looks at *L* through pinholes pricked in the screen at different places in the penumbra, the appearance of *L* will be like that of the sun in a partial eclipse.

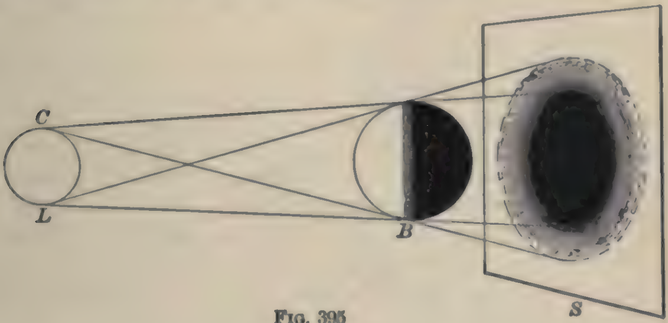


FIG. 395

445. The Formation of Images. — An image is the picture of an object formed by rays of light coming from it. The image that is formed by the rays of light passing through a small opening is always inverted. In Fig. 396, for instance, since the light passes from the candle in straight lines and must pass through the hole in *A* to reach the side of the box *I*, the image must be an inverted one. This is the principle of the pinhole camera.

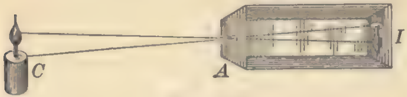


Fig. 396

Experiment 213. — Make a box about 8 in. square on the inside and 1 ft. long. Bore a hole in the middle of one side, and fasten a sheet of tinfoil over it. Darken the room and place a lighted candle in the box. Prick a hole in the tinfoil with a pin and hold a screen at different distances in front of it. Notice that the distance of the screen from the hole regulates the size of the image. Repeat the experiment, using different sizes and shapes of openings in the tinfoil, and note the effect upon the image.

If the tinfoil is pricked full of holes close together until finally there is a hole in the foil a half inch in diameter, it will be seen that the light which comes through forms a series of overlapping images of the source of light.

Experiment 214. — In the box used in the last experiment, saw out a hole 3 in. square in the side opposite to the tinfoil, and fasten a plate of ground glass over the hole. Tack a black cloth around the side containing the ground glass. Fasten on a new sheet of tinfoil, and prick a good-sized hole in it. Throw the cloth over the head, to cut out the daylight, and watch the formation of the images of brightly lighted objects when the pinhole is directed toward them.

446. The Velocity of Light is so much greater than the velocity of any material body that it was long thought to be instantaneous. In 1675, however, Römer, a Danish astronomer, determined the velocity of light by a study of the satellites of Jupiter. One of the moons of Jupiter, in its path around the planet, passes into the shadow of the planet once in 42 h. 28 min. and 36 sec., on the average. Römer observed that the intervals kept increasing in length, while the earth was passing from E to E', and that in six months the retardation amounted to 16 min. 36 sec. This means that it takes the light 16 min. 36 sec. to cross the orbit of the earth; that is, to travel twice the sun's distance from the earth. This gives a velocity of about 186,000 mi. per second.

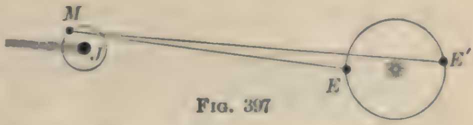


FIG. 397

The determination has been made in other ways, and the results confirm Römer's measurement. We may be able to get a better idea of this velocity by considering that it means that light could travel around the earth nearly 7½ times in 1 second.

447. The Intensity of Light is the quantity of light that falls on the unit of surface. This differs with the source of the light, the distance from the source, and the angle at which the rays strike the surface.

EXPERIMENT 215. — Place a lamp close to a screen through which there is a small hole. At a distance of 1 ft. place a cardboard disk 1 in. in diameter. Place a screen 2 ft. from the light, and the shadow cast by the disk will be 2 in. in diameter, and its area four times that

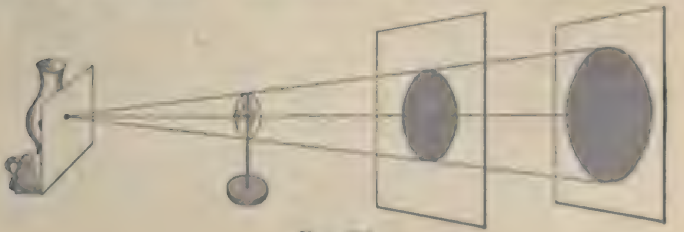


FIG. 398

of the disk. If now the screen is placed 3 ft. from the light, the shadow is 3 in. in diameter, and its area is nine times the area of the disk. In every case the light cut off by the disk would have fallen upon the screen in the area of the shadow.

448. Laws of the Intensity of Light.

I. *The intensity of light upon any surface is inversely proportional to the square of its distance from the source of light.*

II. *The intensity of light is directly proportional to the cosine of the angle of incidence, hence it is a maximum when the ray falls perpendicularly upon the surface.*

Experiment 215 verifies the first law. It can also be deduced as follows: Suppose a source of light to be surrounded by a hollow globe 10 ft. in diameter. Its inner surface will receive all the light sent by the source. If the light is surrounded by a globe 20 ft. in diameter instead, the entire light will be received on the surface of the larger globe, and the comparative intensities will be inversely proportional to the surfaces of the globes, which are as 4 : 1. But the distances of the surfaces from the light are as 2 : 1. Hence the law.

449. Photometry is the process of measuring the relative intensities of light. The standard is the light given by a sperm candle weighing $\frac{1}{6}$ lb. and burning at the rate of 120 grains per hour. Although this is an unsatisfactory standard, other lights are measured by it and rated as being of a certain candle power.

Experiment 216. — Bore a hole in a block, and in it set up a lead pencil. Place this in front of a screen, and place a candle and a lamp or gaslight in such positions that the two shadows of the pencil thrown upon the screen are close together. Move the candle until the shadows are equally dark (Fig. 399). Measure the distance from each light to the screen, and find the candle power of the lamp.

This experiment requires a dark room. The apparatus constitutes a *Rumford's photometer*.

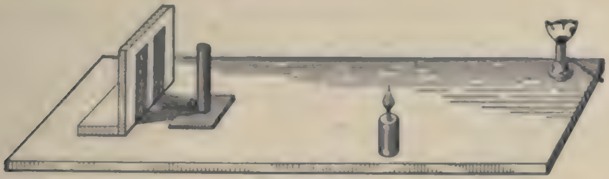


FIG. 399

EXPERIMENT 217.—In the middle of a piece of unglazed white paper put a drop of melted paraffin. Heat it over a lamp until the spot is about half an inch in diameter and transparent. Cut a hole 3 in. in diameter in a thick card, and paste the paper over it with the spot in the middle. Fix this in a vertical position. Set a standard candle on one side and the light to be measured on the other, and when the spot and paper look equally bright from either side, measure the distances from the lights to the screen, and find the candle power of the light.

This form is called the *Bunsen photometer*. It should be used in a dark room.

PRACTICAL QUESTIONS AND PROBLEMS

1. Show by a figure the relative positions of the sun, earth, and moon when there is (*a*) a total eclipse of the sun; (*b*) a partial eclipse of the sun; (*c*) a total eclipse of the moon.

2. Show by a figure how the image of a luminous body is formed on the wall of a darkened room by rays passing through a small hole in the opposite side.

3. Place a wooden ball upon the end of a wire and see how many different forms of shadow it will cast.

4. Do the same with a wooden or cardboard disk. Do the results of these experiments teach anything about the shape of the earth?

5. How soon after any great disturbance takes place on the sun can it be seen on the earth?

6. The light from the nearest fixed star takes 4⅓ yr. to reach the earth. How many times the sun's distance is it from the earth?

7. I can see to read a newspaper easily at a distance of 6 ft. from a lamp. I can see to read equally well 9 ft. from a 16-candle-power gas flame. What is the candle power of the lamp?

8. A 16-candle-power incandescent lamp casts the shadow of a tree on a wall 20 ft. away, while an arc lamp that is 100 ft. farther away from the wall casts an equally dark shadow. What is the candle power of the arc lamp?

9. Does the earth receive more light from the sun in January or in June? Why? Show this by a diagram.

10. The paraffin spot of a Bunsen photometer looks as light as the paper around it when placed between a 16-candle-power lamp on the one side and a 32-candle-power lamp on the other. How far is the photometer from each lamp if the distance between the lamps is 100 ft.?

11. A card 2 in. square held at a distance of 2 ft. from the eye hides a space 2 ft. square on a wall. How far is the wall from the eye?

12. Three inches of the end of a pencil held vertically 2½ ft. from the eye just cover the height of a tree 150 ft. away. What is the height of the tree? What do we assume in taking sight across the end of the pencil and the top of the tree?

LABORATORY WORK

1. Hold a lens in the rays of the sun, and fill the air behind it with crayon dust from two erasers. Observe the converging pencil from the lens to the focus, and the diverging pencil beyond it.

2. Thrust a stout wire into a croquet ball, and hold it in a dark room in such a position that the part lighted by a lamp will represent the phases of the moon from new moon to old. Make drawings of the positions of the observer, the light, and the ball for each phase.

3. Make a box 2 ft. long and 4 in. square on the inside. Fit a piece of tin over one end, and make a small round hole in the middle. Cut a piece of ground glass and fit it in a strip of wood of such size that the glass and base will slip into the box easily (Fig. 400). Line the ground glass off into squares one quarter of an inch on each side with a sharp pencil, and to the base (*a*) fit a handle by which it can be drawn back and forth in the box. Make a scale on this handle so that the distance between the hole in the tin and the ground glass can be read. Point the box toward a window and count the number of squares covered by the image of the window. Read the distance from the hole to the screen. Measure the size of the window and compute the distance between the screen and the window. Verify

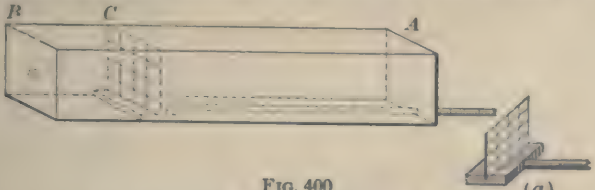


FIG. 400

by measuring the distance directly. Measure the height of a tree by this apparatus.

4. Make a box 3 ft. long and 4 in. square on the inside. About 9 in. from one end fasten to one side a piece of wood having for a cross section an equilateral triangle. Just opposite this place a side

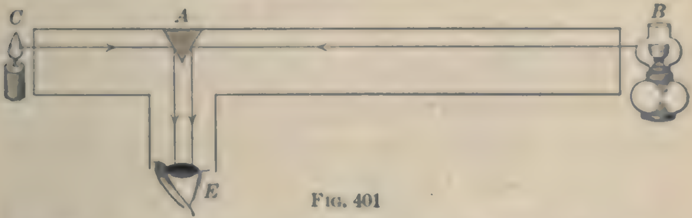


FIG. 401

box (Fig. 401). Cover *A* with white paper. Place a candle at *C*, and a lamp at some point *B*, such that the two sides of the paper shall be equally illuminated, as seen by the eye at *E*. Determine the candle power of the lamp. If the inside of the box and side tube are painted a dead black (use lampblack mixed with turpentine), good work can be done with this photometer.

5. Make a box for the Bunsen photometer, like the one just described. Set two mirrors *M* and *M′* at such angles that the eye will see the reflection of the opposite sides of the spot at the same time. In this way all other light is cut off and the two sides of the screen can be compared easily.

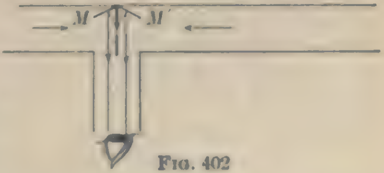


FIG. 402

II. THE REFLECTION OF LIGHT

450. Reflection. — EXPERIMENT 218. — Through a small hole in the shutter of a darkened room admit a ray of sunlight. Lay a mirror in its path and scatter crayon dust or smoke in the air. Observe that the reflected ray is straight and that its direction depends upon the angle at which the ray strikes the mirror.

In Fig. 403, if L is the source of light, MM' the reflecting surface, and P the point at which the light strikes it, then LP is called the *incident ray*, PB the *reflected ray*, the angle LPH the *angle of incidence*, BPH the *angle of reflection*, and PH the *normal* to the reflecting surface. The normal is always perpendicular to the reflecting surface at the point where the ray strikes it.

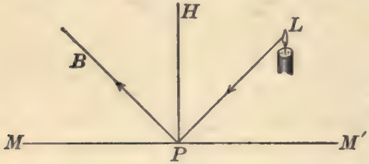


FIG. 403

The relation between the angles of incidence and reflection may be determined by the following experiment:

EXPERIMENT 219. — Select a board about 1 ft. long and 8 in. wide, having the sides AD and HB parallel (Fig. 404). At the middle of side AD fasten a mirror M. Along the other side, HB, fasten a strip of cardboard, the half HC being a quarter of an inch narrower than the half CB. Mark off on HC a scale of equal parts as shown in the figure, numbered from C to H. Lay off an exactly equal scale on the side of CB *facing the mirror*, and number it from C to B. From C draw a line FN perpendicular to the mirror. Make a fine scratch on the silvered surface of the mirror M, so that it shall be exactly over this line. Now place

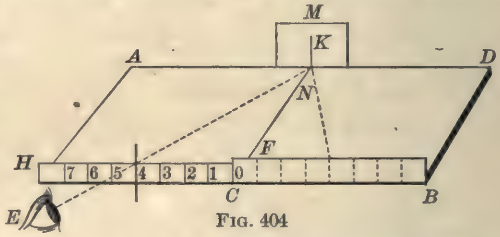


FIG. 404

the eye at E, hold a pin across some division of the scale CH, as 4, and, looking over the top of CH, observe what division of the scale CB is seen to coincide with the line of sight passing from the line K past the pin to the eye. Do this for several divisions and state the law.

451. The Laws of Reflection.

I. *The angle of reflection is equal to the angle of incidence and is in the same plane.*

II. *The plane including the incident and reflected rays is perpendicular to the reflecting surface.*

452. Diffusion. — If the surface upon which light strikes is not a polished surface, the light, instead of being regularly reflected, will be reflected irregularly, and form diffused light. It is by diffused light that we see bodies ordinarily.

EXPERIMENT 220. — Fill a glass nearly full of water, and put in a few drops of milk. Place it in a dark room and put a card with a hole in it over the glass. Let a beam of sunlight into the room and throw it into the glass with a hand mirror. Observe that the globules of milk in the water scatter the light and render the whole glass brilliant.

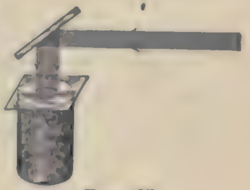


FIG. 405

453. Plane Mirrors and their Images. — A plane mirror is any reflecting surface that is also a plane surface. The surface of still water is a good example. When an object is placed in front of a plane mirror, a *virtual image* of it is formed behind the mirror, and can be seen by an eye placed in the proper position, since the image of an object is in the direction from which the reflected ray comes. This image is called virtual because the effect upon the eye is the same as if the image really existed at that place. The geometrical construction of the image of a point is as follows:

454. To Construct the Image of a Point. — Let A (Fig. 406) be the point of which the image is to be found. Since the angle of reflection is equal to the angle of incidence, the ray AB, perpendicular to the surface, will be reflected upon itself in the direction BA; and the image of the point A will be on BA or AB prolonged. Any other ray AC will be reflected as CE, making the angle of reflection ECD equal to the angle of incidence ACD; and the image will be on CE or EC prolonged. As the lines BA and CE are divergent in front of the mirror, their only point of intersection is at A', a point behind the mirror.

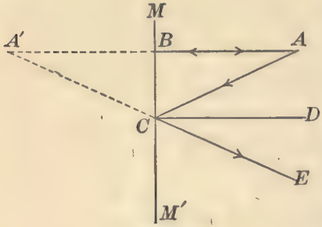


FIG. 406

From the figure the triangles ABC and $A'BC$ are right triangles, the line BC is common, and the angles ACB and ECM' are equal, since $ECD = ACD$. But $A'CB$ also equals ECM'; hence the angle ACB equals the angle $A'CB$, and the triangles are equal in all their parts. Hence $A'B = AB$. This means that *the image of a point in a plane mirror is on a perpendicular from the point to the mirror and as far behind the mirror as the object is in front of it.*

455. To Construct the Image of an Object. — If the object is a straight rod like the arrow AB in Fig. 407, it will be necessary only to determine the position of the image of each end, as all intermediate points will be found on the straight line which joins them. The paths taken by the rays that enter the eye at E may be shown by finding the points C and

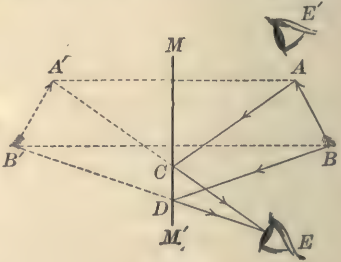


FIG. 407

D, where straight lines from the points *A′* and *B′* to the eye intersect the mirror. The incident rays, then, will be *AC* and *BD*, and the reflected rays will be *CE* and *DE*. When the eye is at *E*, the only part of the mirror used is *CD*.

Suppose the eye to be placed at *E′*. Is the image in the same place as before? Is the same part of the mirror used?

EXPERIMENT 221. — Place a mirror horizontally on a table and look at the image of a candle placed the other side of the mirror from the eye. What kind of inversion is caused by a horizontal mirror?

EXPERIMENT 222. — Stand at a distance in front of a small plane mirror placed *vertically* against the wall. Notice how much of your figure you can see; then walk toward the mirror, and observe whether any greater length of the figure can be seen. Explain.

EXPERIMENT 223. — Stand in front of a plane mirror with the right hand raised. Which hand of the image is raised? What kind of inversion is caused by a vertical mirror?

456. Multiple Images from Mirrors at an Angle. — If two mirrors are placed at right angles with each other, as *M* and *M′* (Fig. 408), the object being at *A* and the eye at *E*, then there will be seen an image *A′* in the mirror *M*, a second image *A″* in the mirror *M′*, and a third *A‴*, which is the image in *M′* of the image *A′* formed by the mirror *M*. The positions of all these images may be found by applying the rule for finding the image of a point in a plane mirror. The paths of the rays that enter the eye may be found as is shown in the figure.

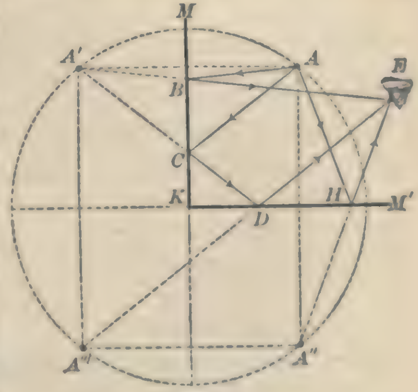


FIG. 408

Multiple images formed in two mirrors that are inclined at a less angle than 90° can be studied by a pair of hinged mirrors, such as are shown in Fig. 409. By standing the mirrors on a table and varying the angle between them, the relation between the angle and the number of images can be showed.

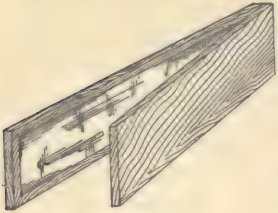


Fig. 409

Experiment 224. — Determine with the hinged mirrors the number of images formed when the angle is 60°; 45°; 30°.

457. Multiple Images from Parallel Mirrors. — If two mirrors *MM'* and *NN'* are placed parallel and facing each other, several images of the candle *C* will be seen by the eye *E*, placed as in Fig. 410. What may be called a primary image, formed by one reflection, will be seen in the direction *EA*, and another of equal brightness in the direction *EA'*. Secondary images, formed by two reflections, will be seen in the directions *EB* and *EB'*. The candle appears at *C'* and *C''*.

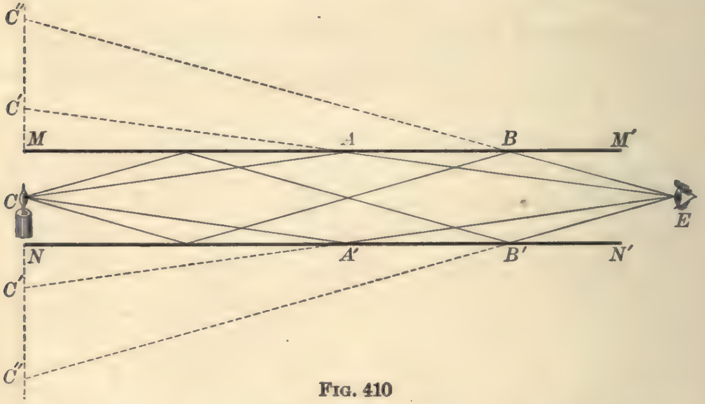


Fig. 410

Experiment 225.—Place four long, narrow strips of mirror inside a wood or pasteboard box, fastening them to the four sides. Make a cover for one end and bore a small hole in the middle of it (Fig. 411). Place the eye at the opposite end of the box and direct the box toward a window. Observe the different images seen from the four sides. Strips of window glass covered with black paper will do very well if mirrors cannot be obtained.

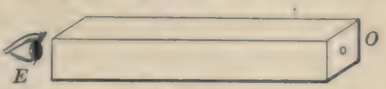


Fig. 411

Experiment 226.—Look through the tube as before, then cover one side of the opening with the finger. Observe whether or not the same side of the different images is covered. From this observation determine the number of reflections that has caused each image.

Experiment 227.—Select a glass tube 18 in. long, and from a half to three quarters of an inch in diameter, and roll around it a smooth sheet of tinfoil. Paste over this a covering of paper. Put a cover over one end, with a hole in it, or put in a rubber stopper with one hole. Place the eye at the other end and look through the tube toward a light. Why does the image of the hole form a circle? Where is the brightest ring? Why? Where are the others? Why?

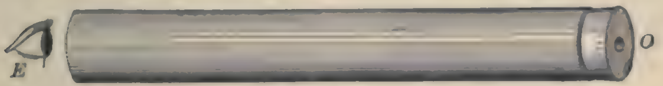


Fig. 412

458. Multiple Images formed by a Plane Mirror.—When light from any source, as the point P (Fig. 413), falls upon a glass mirror, two images will be formed: one at P' from the upper surface MM', and one at P'' from the lower surface NN'. The image P' is generally faint, as but little of the light striking MM' is reflected from that surface,

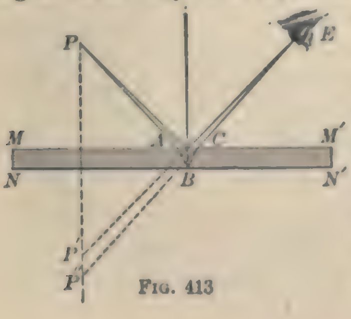


Fig. 413

the most of it passing through to the surface *NN′*, from which, as the glass has a mercury back, it is all reflected. The reason for the bending of the ray at *A* and *C* will be explained under the subject Refraction.

EXPERIMENT 228. — Hold a lighted candle in front of a looking glass in a dark room. How many images do you see? Which is the brightest? Why? Hold the candle so that the rays strike the glass very obliquely. Do any of the images change in brightness? Why?

459. To locate a Perpendicular Line by Reflection. — EXPERIMENT 229. — Saw out a board about a foot long and draw a line *LL′* (Fig. 414) through the middle of it. At one end of the board tack a card with a slit in it so that the slit comes exactly at the end of the line, at *L*. At the other end, *L′*, set up a half knitting needle vertically. At *A*, the middle of *LL′*, fasten a small piece of mirror perpendicular to the board and making an angle of 45° with the line *LL′*. Walk along the line *EB*, holding the instrument in the hand, until, on looking through the slit *S*, the image of a distant point, *C*, is in a vertical line with the needle *N* and the point *B*; then will the line *CA* be at an angle of 90° to *EB*. Why?

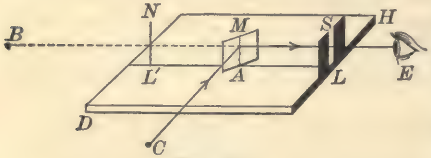


FIG. 414

460. Concave Mirrors may be formed of the concave surfaces of either spheres or paraboloids, hence the sections of concave mirrors by a plane will be arcs of either circles or parabolas. If *C* is the center of the sphere from which the mirror in Fig. 415 is formed, and *MN* the section of the mirror, then *C* is the *center of curvature*, *A* is the *center of the mirror*, *CA* is a *principal axis*, any other axis, as *EB*, is a *secondary axis*, and *MCN* is the *aperture* of the mirror.

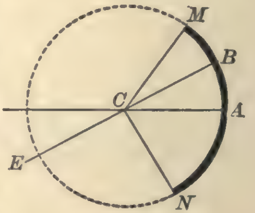


FIG. 415

461. Foci. — A *focus* is a point to which rays of light converge, or from which they diverge. The *principal focus* of a mirror is the point, on the principal axis, in which all rays of light parallel to that axis meet after being reflected from the mirror. The distance of this point from the mirror is the *principal focal length.* A focus is *real* when it is caused by the meeting of rays of light, and *virtual* when rays appear to come from it.

462. Foci of Concave Mirrors. — There are six cases that can be considered.

(*a*) *When the Source of Light is at an Infinite Distance.* — In this case the rays of light will be parallel to the principal axis. The direction of the reflected ray *MF* is determined by drawing the normal from *M* to the center of curvature *C*, and making the angle of reflection *CMF* equal to the angle of incidence *CMD*. This reflected ray will cut the principal axis in *F*, a point practically halfway between *C* and *A*. By a similar construction it can be shown that all parallel rays will pass through *F*; hence this is the *principal focus.*

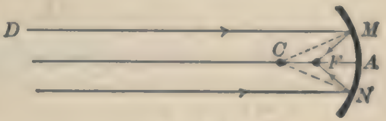


FIG. 416

(*b*) *When the Source of Light is at a Finite Distance beyond the Center of Curvature.* — In this case the rays of light will diverge from the point *P* (Fig. 417). The direction of any ray, as *PM*, after reflection is found by making the angle *CMP′* equal to the angle *CMP*. All rays from *P* striking the mirror will, after reflection, meet at *P′*. The points *P* and *P′* are called *conjugate foci.*

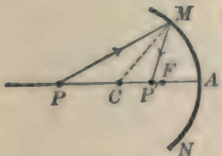


FIG. 417

(*c*) *When the Source of Light is at the Center of Curvature.* — Since every direction from the center of curvature is the radius of the mirror, it is evident that the focus will be found at *C*.

(*d*) *When the Source of Light is between the Center of Curvature and the Principal Focus.* — This is the converse of case (*b*), and by reference to Fig. 417, it will be seen that the focus of *P′* is *P*, a point beyond the center of curvature.

(*e*) *When the Source of Light is at the Principal Focus.* — This is the converse of case (*a*). When the source of light is at *F* (Fig. 416), the direction of every ray after reflection will be parallel to the principal axis, or the focus will be at an infinite distance.

(*f*) *When the Source of Light is between the Principal Focus and the Mirror.* — By making the angle of reflection equal to the angle of incidence, *CMP* (Fig. 418), it will be seen that the reflected rays diverge from the principal axis as though they came from a point *P′* behind the mirror. This forms a *virtual focus*.

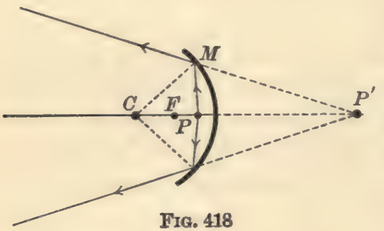


FIG. 418

463. Focus of a Point not in the Principal Axis. — If the source of light is not in the principal axis its focus may be found by the following simple construction. Draw from the point *P* (Fig. 419), a secondary axis through *C*. The ray sent in this direction will be reflected

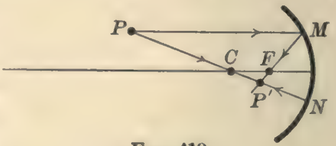


FIG. 419

on itself. Draw a ray parallel to the principal axis, as *PM*. It will be reflected through *F* and its intersection with *NC* will determine the point *P′*, the focus of all rays coming from *P*.

464. Images formed by Concave Mirrors. — The geometrical construction of images formed by concave mirrors is practically the determination of the foci of points. To make this construction but two rays are necessary for each point: the ray passing through *C*, which is a secondary axis, and the ray parallel to the principal axis.

(*a*) *When the Object is at an Infinite Distance.* — Since the focus of all rays parallel to the principal axis is at the principal focus, the image will be at *F*, and will be a point.

(*b*) *When the Object is at a Finite Distance beyond the Center of Curvature.* — Following the rule for construction given above, the points *A′* and *B′* (Fig. 420) are found. These being the extreme points of the image, all other points lie between them. The image is real, inverted, smaller than the object, and between the center of curvature and the focus.

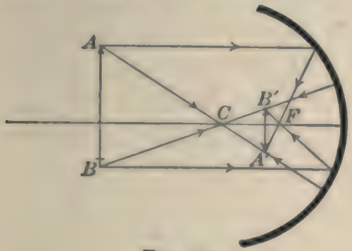


Fig. 420

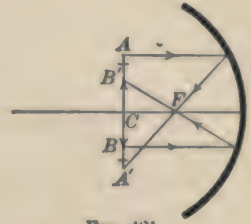


Fig. 421

(*c*) *When the Object is at the Center of Curvature.* — In this case, Fig. 421 shows that the image will be real, inverted, of the same size as the object, and at the center of curvature.

(*d*) *When the Object is between the Center of Curvature and the Principal Focus.* — This is the reverse of case (*b*), and Fig. 422 shows that the image is real, inverted, larger than the object, and beyond the center of curvature.

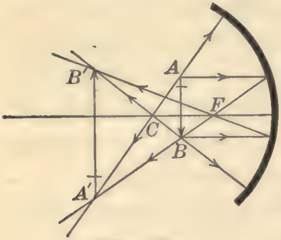


Fig. 422

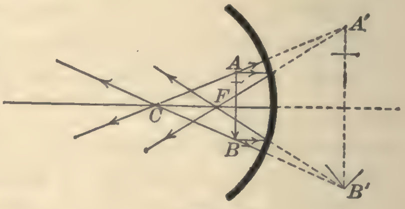


Fig. 423

(*e*) *When the Object is Small and at the Principal Focus.* — This is the reverse of case (*a*). The rays are sent off in parallel lines; hence the image is at an infinite distance away; that is, there is none.

(*f*) *When the Object is between the Principal Focus and the Mirror.* — In this case, as shown in Fig. 423, the reflected rays are divergent, and there can be no real image. By prolonging these rays behind the mirror, however, the image is seen to be virtual, upright, and larger than the object.

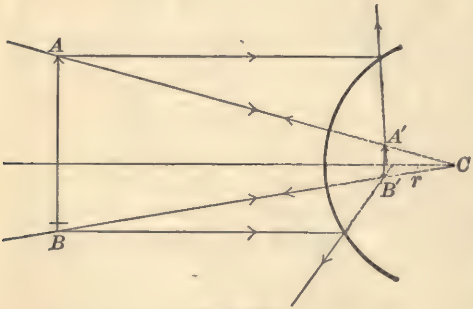


Fig. 424

465. The Convex Mirror. — If the outside of the sphere is made the reflecting surface, the mirror is convex. The focus and image are determined as in the case of the concave mirror, except that the reflected rays must be prolonged behind the mirror before they meet, and hence the image is a virtual one. It is also upright and smaller than the object, as a construction like Fig. 424 will show.

Experiment 230. — Using two mirrors, one concave and the other convex, verify the above conclusions. Remember that the *real* image can be caught on a screen, while the *virtual* can not, but can be seen in the mirror. A piece of ground glass forms an excellent screen.

Experiment 231. — Hang a concave mirror on the wall so that its center is at the height of the eye. Let two students of the same height stand in front of the mirror 10 or 15 ft. away. While one watches the image of the second, let the second walk slowly toward the mirror. By careful observation, student No. 1 can see the inverted image of student No. 2 advance from the mirror and finally rest upon his shoulder, when he is at the center of curvature.

466. Spherical Aberration. — If the angular opening of the concave mirror is large, the principal focus for a parallel ray near the axis will be farther from the mirror than that for one near its edge (Fig. 425). For this reason the outside of an image sometimes looks blurred. To prevent this, the aperture should not exceed 10° or 12°.

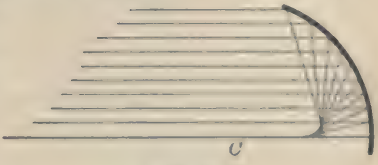


Fig. 425

Experiment 232. — Form in a dark room, with a concave mirror, the image of a candle on a screen. Hold in front of the mirror a screen that cuts off all light except from a circle in the middle about 3 inches in diameter. What effect does this have upon the brightness of the image? Why? What effect does it have upon the distinctness of the image? Why?

PRACTICAL QUESTIONS AND PROBLEMS

1. What advantage is there in considering the angles of incidence and reflection to be the angles which the incident and reflected rays

make with the *normal*, instead of the angles which these rays make with the reflecting surface?

2. What is the angle between a plane mirror and an incident ray when the angle between the incident and reflected rays is 50°?

3. Prove that the shortest plane mirror in which you can see your entire figure when you are standing erect and the mirror is vertical, is one half your height.

4. Construct the images of a point seen in two mirrors placed at right angles to each other. Take the intersection of the mirrors as a center, and the distance from this intersection to the given point as a radius, and describe a circle. Does it pass through all the images? Why? See Fig. 408.

5. Refer to Fig. 410 and determine the distances of *A* and *B* from *C* and *E* respectively.

6. If you should stand in front of a mirror, close the right eye, and stick a piece of paper over the image of the right eye as seen by the left eye, and should then open the right eye and close the left eye, the paper would cover the image of the left eye. Show this by a diagram.

7. How high is the sun above the horizon when a person, standing on the shore of a lake, sees its image by looking at an angle of 60° from the vertical? Make a diagram to show this.

8. Show by a diagram how a person sitting in a second story room can, by using mirrors, see any one who is at the street door.

9. What kind of inversion takes place in images seen in a plane mirror placed vertically? In one placed horizontally?

10. Construct the image of a rod 1 ft. long placed with the lower end 10 in. in front of a plane mirror, and the upper end placed 16 in. in front of it.

11. Under what conditions will the image given by a concave mirror be upright? When will it be smaller than the object?

12. Construct the images of a vertical rod 1 ft. long, placed 16 in., 3 ft., and 8 ft., respectively, in front of a concave mirror whose radius of curvature is 4 ft.

13. Construct the image of the same rod, placed 3 ft. in front of a convex mirror whose radius of curvature is 4 ft.

LABORATORY WORK

1. Write your name so that it will read correctly when seen reflected from a plane mirror.

2. Draw upon a board about 1 ft. square two lines MM' and NN' (Fig. 426), at right angles to each other. Stick a long pin into the board at a point A' on the line NN'. Place a narrow strip of mirror on its edge facing the line MM'. Stick a pin in the front edge of the board at E, and placing the eye so that the pins E and A' are seen in the same line, put a third pin at A on the line NN', so that its image will come on the line EA'. Measure the distances of A and A' from the line MM'. Do these distances verify the law as to the image of a point in a plane mirror?

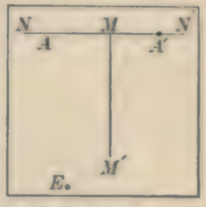


Fig. 426

3. Cut two strips of plane mirror 4 in. long and 1 in. wide. Fix these in a vertical position so that they make an angle of 30° with each other. Place the eye at the upper end of the strips, and some pieces of colored paper in the angle between the mirrors at the lower end. Observe that the reflection gives a geometrical design, and also notice that this is never repeated. Why?

4. Take a concave mirror into a dark room and place it vertically upon a table. Make a scale of equal parts upon a piece of ground glass. Place this in front of the mirror, and hold a gas flame back of it. Receive the image of the scale upon a second similar scale. Change the respective positions of the lighted scale and the one upon which the image is received, until the image of the scale exactly coincides in size with the scale upon the screen. Measure the focal length of the mirror.

5. Paste paper over the convex surface of a convex mirror. Make two holes A and B (Fig. 427) in the paper at equal distances from the middle of the mirror. Place it so that the sun can shine upon it through an opening in the screen HK. The rays falling on A and B will be reflected at H and K as bright spots. By changing the position of the screen such a position can be found that $HK = 2\,AB$, when LM is equal to the principal focal distance of the mirror. Why?

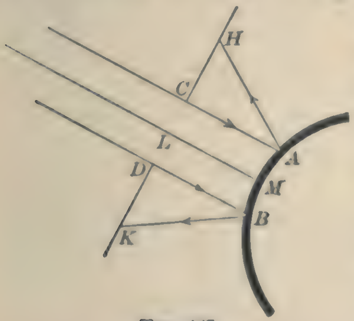


Fig. 427

III. The Refraction of Light

467. Refraction. — Experiment 233. — Fill a rectangular glass tank (a battery jar will do) nearly full of water, to which add a few drops of milk. Make a pasteboard cover for one end of the jar. Make a hole *C* (Fig. 428) in this pasteboard, and by means of a hand mirror direct a beam of sunlight against it. Observe that if the beam is thrown in the direction *AC* perpendicularly against the side, it passes through without change of direction; but if its direction is *BC*, or *EF*, the ray bends down just at the point where it strikes the water.

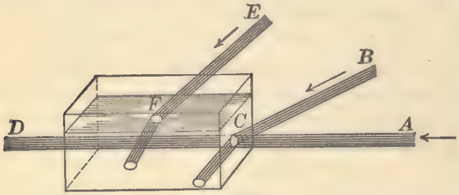


Fig. 428

This bending of a ray of light on passing from one medium into another is called *refraction.*

468. Angles of Incidence and Refraction. — Let the incident ray *AB* (Fig. 429) strike the surface of water at *B.* On passing into the water, the refracted ray will take the direction *BC.* Draw the normal *DE* to the surface at *B*; then the angle *ABD* is called the *angle of incidence* and the angle *EBK* the *angle of refraction.* The angle *CBL*, which is the difference between the angles of incidence and refraction, is the *angle of deviation.* The lines *FG* and

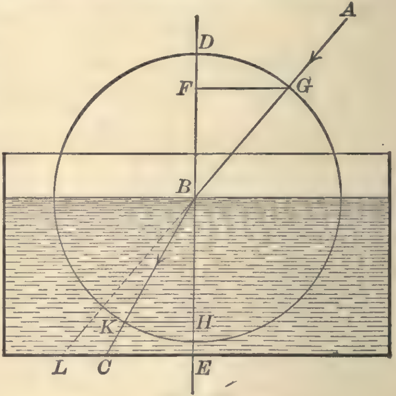


Fig. 429

HK drawn perpendicularly to the normal *DE* are the ***sines*** of the angles of incidence and refraction respectively if we consider the radius *BG* to be unity. The ratio of the sine of the angle of incidence to the sine of the angle of refraction is called the ***index of refraction***. In Fig. 429 the index of refraction is $\frac{FG}{HK}$.

469. The Laws of Refraction.

I. *When a ray of light passes from a less refractive to a more refractive medium it is bent toward the perpendicular to the surface at that point. When it passes from a more refractive to a less refractive medium it is bent from the perpendicular.*

II. *The incident and refracted rays are in the same plane.*

III. *Whatever the incident angle, the index of refraction for any two media is a constant quantity.*

Experiment 234. — Cover the side of the tank used in Experiment 233 with paper from the middle of which a large circle has been cut. Draw in ink a vertical diameter *AB* (Fig. 430) and a horizontal one *CD*. Fill the tank with water to the line *CD*. Put a cover over the top, and through a narrow slit send a beam of light so that it will meet the water directly behind the intersection of the diameters. Measure *FG* and *HK* for different angles of incidence, and the ratio will be found a constant.

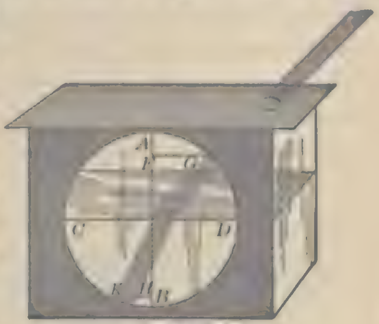


Fig. 430

470. Cause of Refraction. — When a beam of light moving in one medium strikes the surface of another, its velocity is changed. If the new medium is more refractive, or optically denser, than the old, the velocity will decrease, while if it is less refractive, or optically rarer, the velocity will increase. Suppose the beam has the wave front *LF*, and is moving in the direction *CD*. When the ray *EF* meets the surface *xy* its velocity, in the new medium, will diminish, and by the time the ray *AL* has reached *B* it will have gone only the distance *FG* from *F*, the ray *CD* will have reached *H*, the new wave front will be *BG*, and the new direction will be *DH*.

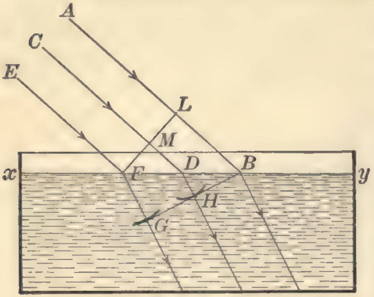


Fig. 431

471. Indices of Refraction. — Since the ether is the real medium for the transmission of light, and since the velocity is greater in ether alone (*i.e.* in a vacuum) than in ether associated with any kind of matter, there are two kinds of indices of refraction: one is the *absolute index*, shown when the ray passes from a vacuum into a substance; the other is the *relative index*, shown when the ray passes from one substance into another. The relative index of two substances is found by taking the inverse ratio of their absolute indices.

Table of Absolute Indices of Refraction (Yellow Light)

Substance	Index	Substance	Index	Substance	Index
Vacuum	1.00000	Alcohol	1.360	Flint Glass	1.651
Air	1.00029	Carbon Bisulphide	1.624	Diamond	2.47 to 2.75
Water	1.334	Crown Glass	1.516	"	

The index of refraction is not the same for lights of different colors. The indices given above are for yellow light. For the purposes of this book the index of refraction for light passing from air to water will be taken as $\frac{4}{3}$, to crown glass $\frac{3}{2}$, to flint glass $\frac{8}{5}$, and to diamond $\frac{5}{2}$.

472. Total Reflection; Critical Angle. — EXPERIMENT 235. — Fill the tank used in Experiment 233 with water, and by means of a mirror *M* (Fig. 432) direct a ray of sunlight through an opening, *O*, in the pasteboard end near the bottom, so that it will strike the surface of the water. By changing the direction of the ray a point *S* may be found such that if the ray strikes the surface of the water to the right of *S* it will pass through this surface, but if it strikes at *S*, or to the left of *S*, it will be totally reflected, making the angle *NSR* = angle *NSO*.

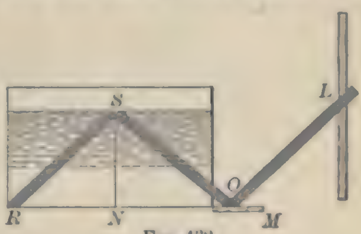


FIG. 432

That angle of incidence at which the ray, instead of passing into the air, shall just graze the surface of the water, is called the *critical angle*, and varies with the media. The critical angle for light passing from water into air is about 48.5°; from crown glass into air, 42°; and from diamond into air, 24°.

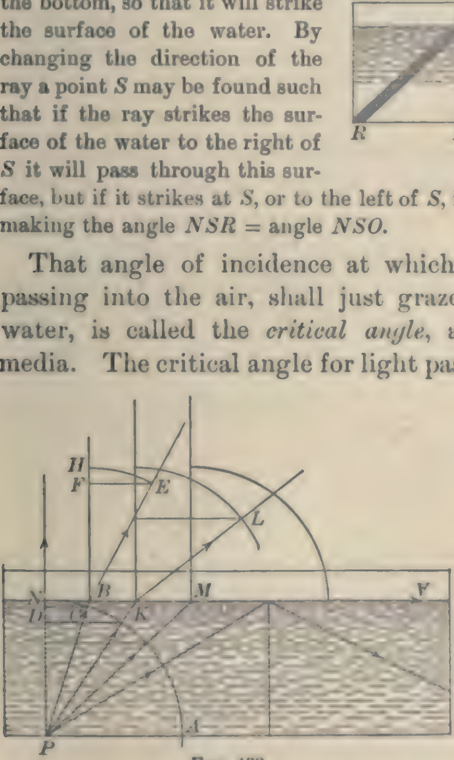


FIG. 433

473. Cause of Total Reflection. — If a point *P* is placed at the bottom of a vessel of water (Fig. 433), it will send rays of light in all directions and the path of any of them can be traced by applying the law for refraction. To construct the path of any ray take the point *P* as a center and with any radius as *PN* draw an arc *NA*. Draw the ray *PB* at an angle of, say, 18° from the normal, and with the point *B* as a center and *PN* as a radius describe an arc cutting the normal *BH* at *H*. Draw the sine of the angle *BPN*. It is *CD*. Lay off the sine *FE* equal to $\frac{4}{3}$ *CD*; then will the line *BE* determine the direction of the refracted ray. The direction of other rays can be determined in the same way, as *PKL*. It is evident that when the sine of the incident ray from *P* multiplied by $\frac{4}{3}$ is equal to the radius *PN*, the refracted ray will just skim along the surface of the water, as *PMV*. Beyond the point *M* the ray will be totally reflected, according to the usual law.

The entire space above the surface of the water would be seen, by an eye placed beneath the surface, within a circle limited by a cone of rays the angle of which is 97°. Beyond that circle, the surface of the water acting as a total reflector would reflect the bottom and things lying upon it.

Experiment 236. — While sitting at a table, hold a glass of water high above the head. Observe the images of bodies upon the table. Notice that you cannot look through the surface. Put a spoon into the glass and notice that the part in the water is reflected from the surface.

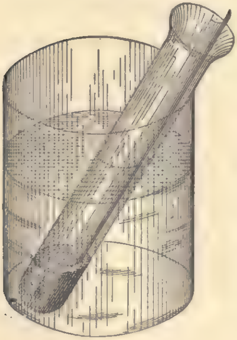


Fig. 434

Experiment 237. — Fill a beaker two thirds full of water. Into this thrust a test tube with a slip of paper in it. Notice that there is a position at which total reflection takes place and the paper cannot be seen through the water. Pour a little water into the test tube, and notice that wherever the inside of the tube is wet the paper can be seen. Explain.

474. Effects of Refraction. — Whenever a straight stick is placed in water at an angle, as *AB* (Fig. 435), it appears bent at the surface of the water *D*, the part *BD* below the surface seeming to rise, the end *B* taking the position *C*. This effect is due to the refraction of the ray *BF* at *F*, where it takes the direction *FE*, and since the apparent position of a body is in the direction of the ray that enters the eye, the point *B* is seen at *C*.

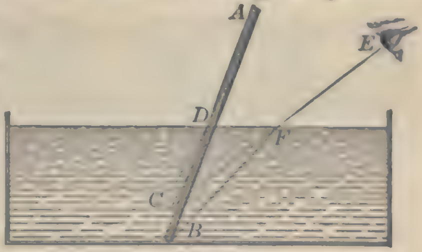


Fig. 435

For the same reason a pond into which a person looks in a slanting direction seems to be shallower than it really is.

Refraction takes place in gases also, when rays pass from one medium into another of different density. This gives rise to two effects at sunrise and sunset.

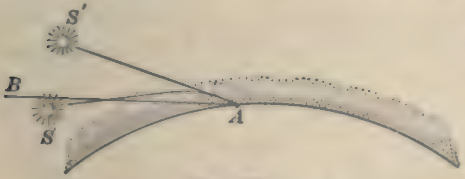


Fig. 436

First.—The sun is seen when it is really below the horizon. If the line *AB* (Fig. 436) represents the horizon at the point *A*, the sun, though below it, at the point *S*, appears to be at the point *S′*: for the rays from *S*, on striking the atmosphere of the earth and constantly passing into denser layers, are bent downward, and as the ray that enters the eye is from the direction *S′A*, this locates the sun at *S′*.

Second.— Another effect is that upon the apparent shape of the sun. The rays that are nearest the horizon are bent the most, so that the lower side appears higher than it really is, with reference to the upper side. This causes the lower side to appear more flattened than the upper. This effect is shown in Fig. 437, which represents photographs of the rising sun, at four elevations.

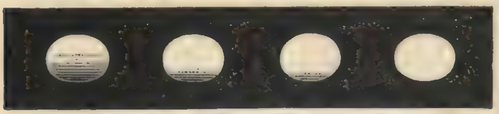


FIG. 437

475. Refraction through Plates with Parallel Sides. —

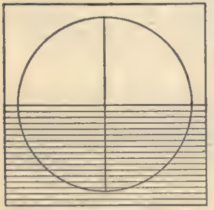


FIG. 438

EXPERIMENT 238. — Upon a card draw a circle with two diameters at right angles to each other. Place a piece of plate glass or of thick window glass over the card as in Fig. 438. As long as this is looked at perpendicularly to the card no distortion is seen, but if it is turned so that the line of sight is not perpendicular to the card, there is seen a break in both sides of the circle and in the vertical diameter.

When light strikes the side of a transparent plate with parallel sides, as at *E* (Fig. 439) it is bent toward the normal at *E*, taking the direction *EH*, which is determined by the relative index of refraction, that is, the ratio $\frac{\sin i}{\sin r}$. When the light reaches *H* it is bent away from the normal in the direction *HK*, which is determined by the ratio $\frac{\sin i'}{\sin r'}$. But this ratio, by the laws of refraction, is the reciprocal of the first ratio; and from the figure $r = i'$. Hence $i = r'$, and the direction of *HK* is parallel to *LE*.

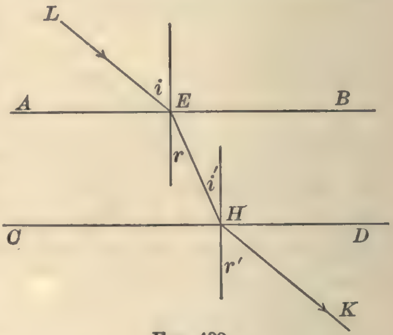


FIG. 439

476. Prisms.—If the surfaces of the transparent medium are not parallel, the emerging ray will not be parallel to the incident ray. When the cross section of the medium is a triangle the medium is a prism. The path of a ray passing through a prism is shown in Fig. 440. When the ray from L strikes the prism at D it is bent toward the normal and passes through the prism in the direction DH. When it passes out of the prism at H it is bent from the normal in the direction HK. Since the ray is bent twice in the same direction it is seen that *a ray of light passing through a prism is bent toward the base.* If the eye is placed at K, the source of light will be seen at L'. The position of any object seen through a prism is apparently moved toward the *refracting angle*, which is the angle formed by the intersection of the two faces under consideration.

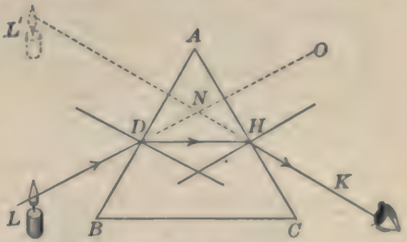


FIG. 440

The *angle of deviation* is the angle which the incident and emergent rays form with each other. In Fig. 440 it is the angle KNO. This angle varies with the refracting angle of the prism, the index of refraction of the medium, and the angle of incidence. There is for every prism a minimum angle of deviation, and this is obtained when the angles of incidence and emergence are equal.

477. Lenses. — A lens consists of a transparent body bounded by two surfaces, one or both of which are curved. The curved surfaces are usually spherical. There are six forms of lenses in common use, which may be classified in two groups of three each:

1. Double convex	**Converging lenses.** **Thicker in the middle than at the edge.**
2. Plano-convex	
3. Converging meniscus	
4. Double concave	**Diverging lenses.** **Thinner in the middle than at the edge.**
5. Plano-concave	
6. Diverging meniscus	

These lenses may be considered as being formed as follows:

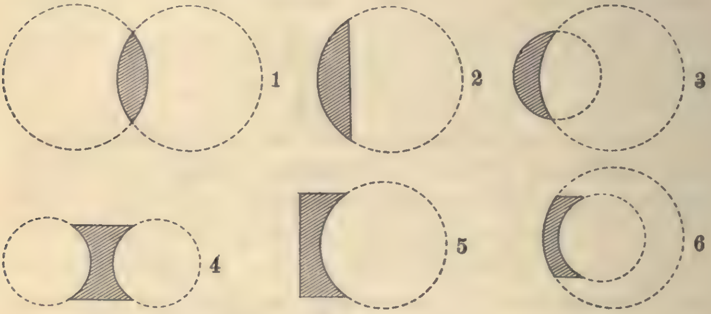


FIG. 441

1. Intersection of two spheres.
2. Intersection of plane and sphere.
3. Intersection of small sphere by large sphere.
4. Intersection of cylinder by two spheres.
5. Intersection of cylinder by plane and sphere.
6. Intersection of cylinder by two spheres.

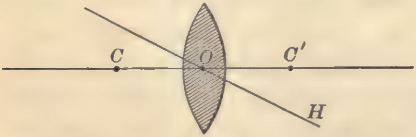


FIG. 442

478. Center of Curvature; Principal Axis; Optical Center. — The centers of the spheres whose surfaces bound a lens are its *centers of curvature*, as C and C' (Fig. 442). The straight line passing through these centers is the *principal axis* of the lens. In the plano lenses the principal axis is a line passing through the center of curvature of the curved surface, and normal to the plane surface. The *optical center* of a lens is that point through which a ray of light passes with practically no change in its direction. In a double convex lens having the same curvature for both sides, it is the center of the figure. In plano lenses it is at the intersection of the curved surface and the principal axis. Any ray which passes through the optical center, but does not pass through the center of curvature, is a secondary axis, as *HO* in Fig. 442.

479. The Path of a Ray through a Lens. — Suppose the ray to come from the point *P* on the principal axis and to strike the lens at the point *A* (Fig. 443). The direction *AB* through the lens may be found as follows:

Describe from *A* as a center two arcs of circles with radii that are to each other as 3 : 2 ($\frac{3}{2}$ being the index of refraction of the lens). From *E*, the intersection of the ray with the arc *DE*, draw a line parallel to the normal *C′A*, and from *H*, where the parallel intersects the second arc, draw *HA* and prolong it to *B*.

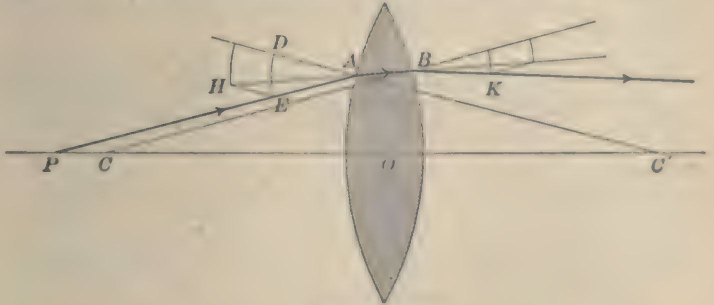


FIG. 443

In a similar way determine the direction, *BK*, that the ray will take on emerging from the lens.

480. The Foci of Convex Lenses. — The positions of the luminous point for which we may determine foci in convex lenses are similar to those considered for concave mirrors. The determination of the focus of any point requires the drawing of the paths of two rays only. If the luminous point is on the principal axis, that is taken as the path of one ray. If it is not, a secondary axis is drawn.

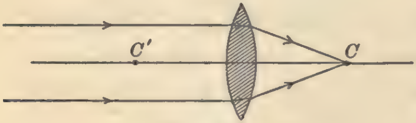


FIG. 444

(*a*) *When the Luminous Point is at an Infinite Distance.* — In this case the incident rays are parallel, and if we take the index of refraction as $\frac{3}{2}$, the focus is very near the center of curvature for a double convex lens, and at twice that distance for a plano-convex lens. This is the *principal focus*, and its distance from the lens is the *focal length* of the lens.

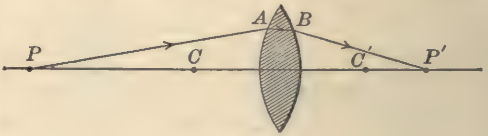


FIG. 445

(*b*) *When the Luminous Point is at More than Twice the Focal Length.* — If the path of the ray *PA* is constructed, it will be found to intersect the principal axis at P', between C' and twice the focal length.

(*c*) *When the Luminous Point is at Twice the Focal Length.* — A construction will show that the focus is also at twice the focal length on the other side of the lens. These points constitute *conjugate foci.*

(*d*) *When the Luminous Point is at Less than Twice and More than Once the Focal Length.* — This is the converse of (*b*), as is shown in Fig. 445, since if the luminous point is P', its focus will be P.

(*e*) *When the Luminous Point is at the Principal Focus.* — This is the converse of (*a*), and the emergent rays will be parallel to the principal axis.

(*f*) *When the Luminous Point is between the Principal Focus and the Lens.* — In this case the rays will emerge as divergent rays, and the focus will be virtual, on the same side of the lens as the luminous point, and farther away from the lens.

Converging lenses render parallel rays converging, increase the convergence of converging rays, and decrease the divergence of diverging rays, or render them parallel or converging.

481. Formula for Convex Lenses. — The relative positions of a point and its image can be determined if the principal focal length is known. This relation is expressed by the formula

$$\frac{1}{f}=\frac{1}{p}+\frac{1}{p'}, \tag{60}$$

in which f is the principal focal length, p the distance of the point P from the lens, and p' the distance of its image from the lens.

482. The Foci of Concave Lenses. — (*a*) *When the Incident Rays are Parallel.* — In this case the rays emerge as divergent rays (Fig. 446), and the focus is virtual. In the double concave lens (crown glass) the focus is at the center of curvature; in the plano-concave (crown glass), at twice that distance from the lens.

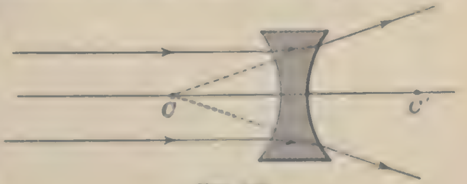


FIG. 446

(*b*) *When the Incident Rays are Diverging.*—In this case a construction will show that the emergent rays are more diverging, and that the virtual focus is nearer the lens than in case (*a*).

(*c*) *When the Incident Rays are Converging.*—In this case the rays are rendered less converging, and the position and kind of focus (if any) will depend upon the amount of convergence in the incident rays.

Diverging lenses render parallel rays diverging, increase the divergence of diverging rays, and decrease the convergence of converging rays, or render them parallel or diverging.

483. The Formation of Images by Lenses. — EXPERIMENT 239.—Take a convex lens, a candle, and a screen into a dark room. Place the three on a table as in Fig. 447, and by varying the relative distances study the images of the candle formed on the screen by the lens. Since the image of an object is made up of the foci of all its points, verify the positions given for these foci in § 480.

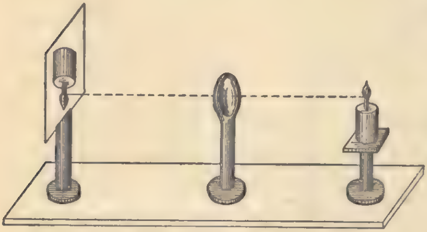


FIG. 447

484. Geometrical Construction of Images. — The image which any lens will give of an object can be constructed with great accuracy. To do this two rays only are needed from each end of the object. These rays are the secondary axis, which will pass through the optical center of the lens, and a ray parallel to the principal axis, which, after passing through the lens, will pass through its principal focus. The image of the arrow *AB* (Fig. 448) formed by the lens *D* will be *A′B′*. The parallel ray *AG*, passing through the lens in the direction GH, will then pass through C'', and its intersection with the ray AO

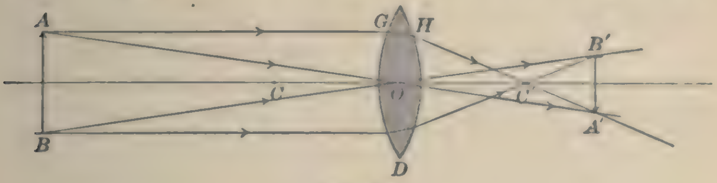


FIG. 448

continued will give the image of A at the point A'. The image of B can be found in the same way.

485. Spherical Aberration. — The rays that pass through a convex spherical lens near the edge do not focus at the same point as those that pass through near the middle of

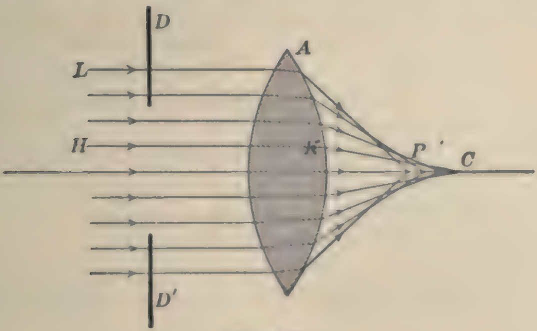


FIG. 449

the lens. This can be shown by construction as in Fig. 449. The ray LA comes to a focus at P, and only those rays quite near the center focus at C. The effect of this is to make the outside of the image indistinct when the center is distinct, and *vice versa*. This defect may be remedied by using a diaphragm with a hole in it, in front of the lens, as DD'. This makes the image more distinct, but as it cuts off the light from the outside, the image is not so bright.

PRACTICAL QUESTIONS AND PROBLEMS

1. Suppose P to be a luminous point at the bottom of a dish filled with water to the line AB. Construct the paths of the rays PC, PD, etc., making angles of 10°, 20°, 30°, etc., with the normal PN. Trace as many of these paths as will strike on the surface AB. Let AB be 10 in. long and the water 6 in. deep.

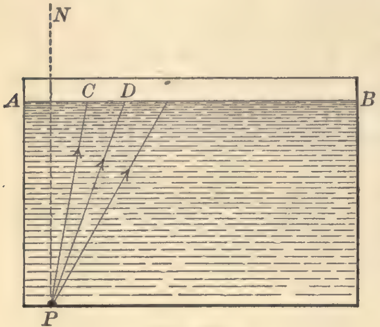


FIG. 450

2. Suppose you place a block of glass (index of refraction $= \frac{3}{2}$) 2 in. thick, upon a point P, resting on the table. Construct the paths of rays passing from it at the same angles as PC, PD, etc., in No. 1.

3. Explain why the amount of light reflected from a diamond is greater than that from a piece of glass cut in the same shape.

4. Why does an oar placed in the water appear bent?

5. Why is there a difference between the apparent diameters of the full moon when it is rising and when it is well up in the sky?

6. Why does a vertical straight line, when looked at in a slanting direction through a piece of ordinary window glass, appear to be full of short bends, while if it is looked at through a piece of plate glass it appears straight?

7. Prove that a ray of light passing through a prism is bent toward the base.

8. Construct the path of the emergent rays of a double convex lens when the luminous point is between the principal focus and the lens.

9. Construct the paths of the rays emerging from a double concave lens when the incident rays are diverging.

10. The radius of curvature of each surface of a double convex lens is 2 ft. Construct the image it forms of an arrow 3 ft. from the lens.

11. When the image of an object 18 in. from a convex lens is thrown upon a screen at a distance of 5 in. from it, what is the focal length of the lens?

12. Find the focus of a point 24 cm. from a convex lens when the focal length is 18 cm.

LABORATORY WORK

1. Fill a rectangular tank, like a battery jar, nearly full of water. Put one end of a glass tube or wooden rod into the water, and place yourself in such a position that you can see it through the surface of the water, the side of the tank, and the end of the tank, at the same time. Explain.

2. Attach a weight W to a wooden ball B, and put it in a tank of water (Fig. 451). Place the eye at E, vertically above the ball, and then at E' so as to see the ball at an angle. Show by a figure the reason for the difference in the appearance of the ball.

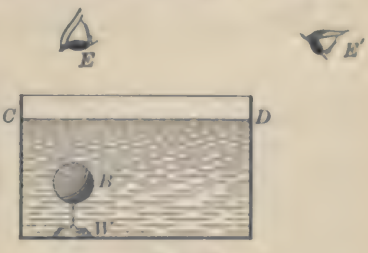


FIG. 451

3. Empty the rectangular tank used in No. 1 and in one corner, or at the middle of one side, place a coin as at C (Fig. 452). Fix a meter stick vertically at M, and take the reading of the point E, where a line from C just touches the top of the tank at A, and below which C cannot be seen. Fill the tank with water and read the point E', at which the edge of the coin can just be seen. Take measurements of the tank and make a drawing, from which compute the index of refraction from water to air.

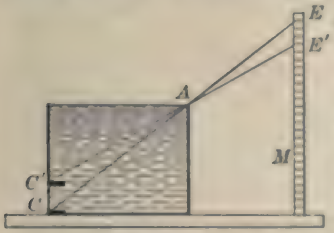


FIG. 452

4. Set two cardboard screens S and S' (Fig. 453) on a table, and in one of them make a small hole A. Set an alcohol lamp upon the table and sprinkle some salt on the wick. The lamp will then give a yellow light. Mark the point B on the screen S' where the rays from L strike after passing through the hole in S. Place just behind the hole a prism *P*, and mark the point *C* where the rays now strike Measure all required distances and determine the angle of deviation.

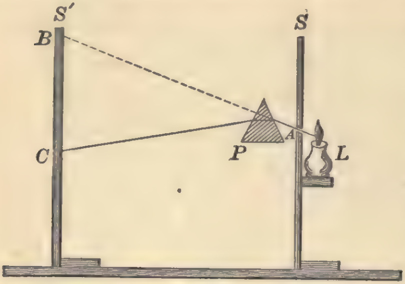


FIG. 453

Rotate the prism on an axis parallel to the table and to the screens, and you will observe that the point *C* will move up toward *B*, and then, although you turn the prism in the same direction, the point will turn and go down again. This shows that there is one particular angle of incidence at which the angle of deviation is least. This is called the *minimum deviation*. At that point what is the relation between the angle of incidence and the angle of emergence?

5. In one side of a small wooden box or cask bore a 2-in. hole near the bottom. Just opposite to this bore a half-inch hole and fit it with a short brass tube. Fit a large cork to the 2-in. hole and mount in it as large a lens as you can, so that when a beam of sunlight is sent through it the focus will be inside the brass tube. Now fill the cask with water and send the beam of sunlight through the lens, and the whole stream passing out the brass tube will be illuminated. Why? Make the stream a smooth one by rounding out the inside of the outer end of the brass tube. Introduce a colored glass plate at *A* and observe.

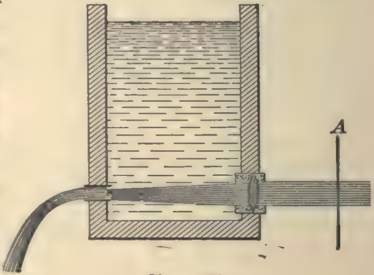


FIG. 454

6. Make a similar experiment with a glass rod or tube bent as in Fig. 455. Hold one end toward a flame and look in the other end. The entire end is aglow. Show the reason for this by a figure.

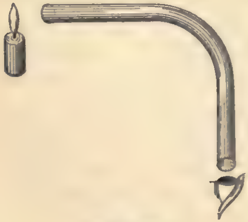


FIG. 455

7. Fasten a sheet of paper upon a table and draw a straight line across it, as *MM*

(Fig. 456). Set a thick piece of plate glass on its edge so that one face is on the line *MM'*. (If the plate glass is not very thick, clamp two or three pieces together.) Paste a piece of paper on the back of the glass with a line drawn on it so as to be vertical when the glass is in place. Mark the bottom of this line, as at *A*. Place the eye at the other edge of the table at *E* and stick a pin in the paper at *C* and another at *B* in line between the eye and the line of sight to the line *A*. Remove the glass and describe a circle with the point *B*—on the line *MM'*—as center and *BA* as radius. Complete the figure and find the ratio of *KD* to *AH*. What is this ratio?

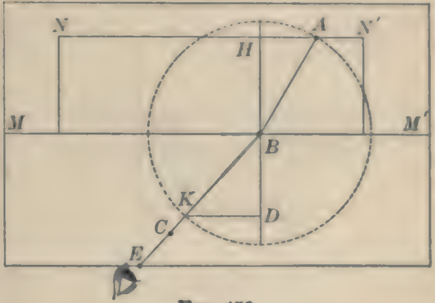


FIG. 456

8. The cross section of a given prism is a right triangle. Suppose a ray of light to strike perpendicularly against the middle of one of the sides forming the right angle. Construct the path of the ray through the prism and also its direction on passing from the prism into the air.

9. Take a convex lens, candle, piece of ground glass with a centimeter scale marked on it, and a screen into a dark room. Place the screen on one side of the lens, and the ground glass scale on the other. Place the candle close behind the scale and move the screen until the distinct image of the scale falls upon it. Measure the length of the image and measure the distances of the scale and the screen from the lens. Repeat with the scale at different distances, and find the relation of the distance of the image to the distance of the object from the lens.

10. Substitute the distances obtained in the preceding experiment in the formula for convex lenses and find the focal length of the lens you have been using. Take the average of all your determinations and verify by taking the lens into the sunlight and finding the image of the sun.

IV. Dispersion and Polarization

486. The Dispersion of Light. — Experiment 240. — Take a prism into a dark room and hold it in front of a horizontal slit in a shutter. When a beam of sunlight passes through the prism it is not only refracted, but separated into a band of colors on the opposite wall.

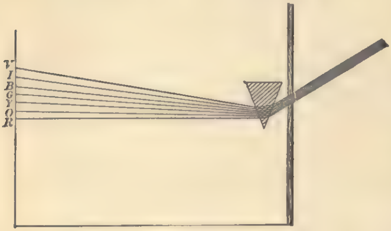


Fig. 457

This *dispersion* is due to the fact that the index of refraction in a glass prism varies with the wave length.

The spectrum formed is called the *solar spectrum*, and consists of a series of colors passing imperceptibly from violet, which is refracted the most, through indigo, blue, green, yellow, and orange, to red, which is refracted the least.

Experiment 241. — Paste two narrow bands of paper, one violet and the other red, upon a black card, and look at them through a prism. It will be seen that the red rays are refracted less than the violet.

487. Recomposition of White Light. — Since the spectrum is formed by the unequal dispersion of white light, it is possible to reproduce white light by bringing all the spectrum colors to one place. This can be done by using a second prism reversed, a concave mirror, or a convex lens.

Experiment 242. — Set up a prism in a dark room and let the sunlight strike it through a slit in the shutter. Let the spectrum fall upon a double convex lens placed at about its focal length from the wall. The spectrum colors being brought together at the point P (Fig. 458) will produce a brilliant white spot.

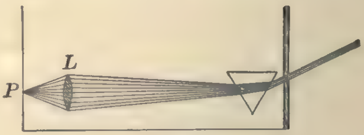


Fig. 458

488. Chromatic Aberration. — EXPERIMENT 243. — Place a large double convex lens perpendicular to the sun's rays (Fig. 459). If a screen is placed at *S*, a picture of the sun will be formed having an outer fringe of *red*, but if the screen is placed in the position *S′* the fringe will be *violet.*

This effect, which is quite common in single lenses, is called *chromatic aberration*, and is due to the unequal refraction of the different colors.

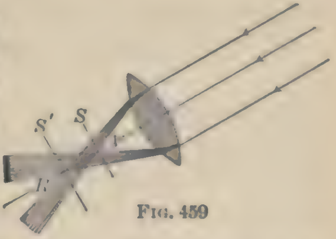


FIG. 459

489. The Achromatic Lens. — Achromatism, or the formation of images without colored fringes, is secured by combining a plano-concave lens of flint glass with a double convex lens of crown glass. These are of such curvatures that the dispersion of one is neutralized by that of the other, while the refraction is retained. The refraction of the combination is less, however, than that of the double convex lens alone.

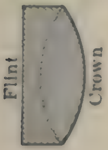


FIG. 460

490. The Rainbow. — One of the most familiar and striking results of refraction and dispersion in nature is seen in the rainbow. Whenever rain is falling and the sun is shining upon it, from a point not too high in the heavens, an observer standing with his back to the sun will see one and sometimes two of these brilliant bows.

The inner or *primary bow* is composed of the spectrum colors in their order, the red being on the outside and the violet on the inside. The outer or *secondary bow* is composed of the same colors, but in an inverse order.

491. The Primary Bow. — When a beam of sunlight *L* strikes upon a raindrop at *A* (Fig. 461), the light that passes into the drop is refracted at A and dispersion begins at the same place, so that when the light strikes the back of the drop it is as a spectrum, with the red ray above on account of its refraction being the least. At RV part of the light passes out of the drop, but part is reflected. Since the angle of incidence ARO is greater than the angle AVO, the angle of reflection ORR' must be greater than the angle OVV', and for this reason the rays will cross at B and emerge (in part) from the drop at R' and V' in the directions $R'R''$ and $V'V''$. The other spectrum colors will be refracted in regular order between R'' and V''.

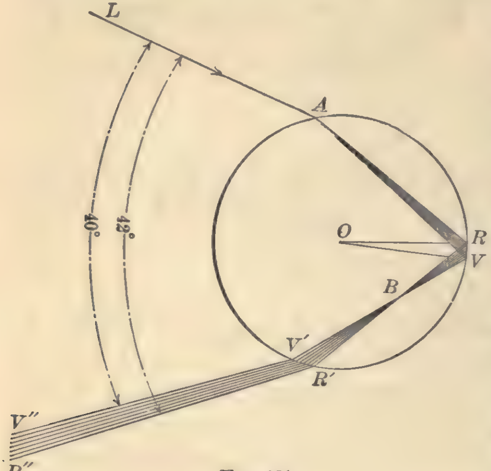


FIG. 461

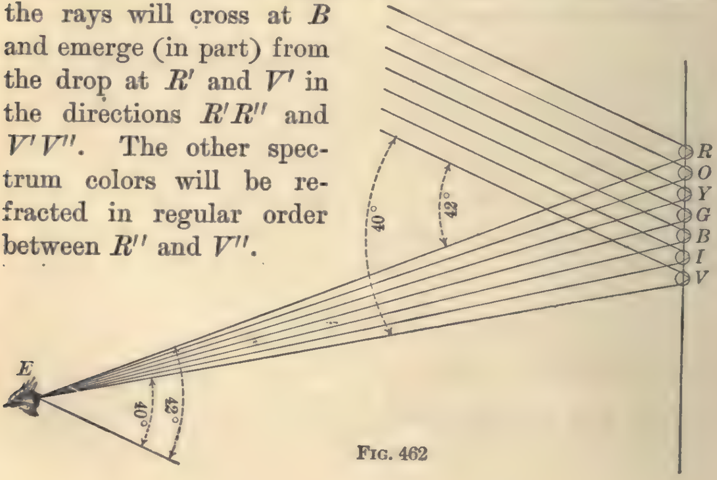


FIG. 462

The angle of incidence at which these results are obtained is such that the red ray leaves the drop at an angle of 42° to the direction of the entering ray, and the violet ray at an angle of nearly 40°. Hence the red ray is seen at an angle of 42° and the violet at angle of about 40° to a line drawn from the observer directly away from the sun.

Since the angle for the red ray is two degrees more than for the violet, it is evident that if the eye is placed at *E* (Fig. 462) the different colors will be seen reflected from different drops, and that the drop giving the red ray will be higher than any of the others. This explains why the red is on the outside of the primary bow.

492. The Secondary Bow. — The sun's rays striking on the lower side of the raindrop at *A* (Fig. 463) will be refracted and dispersed to *VR*, and then after two reflections part of them will emerge from the drop, the red at an angle of 51° and the violet at an angle of 54° to the direction of the entering ray. This means that the eye will receive the violet ray from a higher elevation than the red ray, and hence that the violet will be on the outside of the secondary bow.

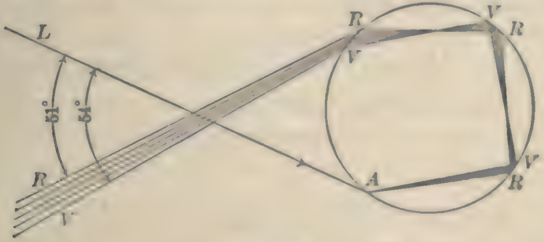


FIG. 463

493. Why the Rainbow is Circular. — Since the raindrop is a sphere, the red rays of the primary bow are sent off in the form of a cone having the drop at its vertex and making an angle of 42° with the axis of the cone. The red ray, therefore, can be seen, from different drops, in any direction that makes an angle of 42° with the axis of the bow, that is, with the line that passes through the sun and the eye of the observer; and hence its form will be circular. In Fig. 464 the sun is supposed to be at the horizon.

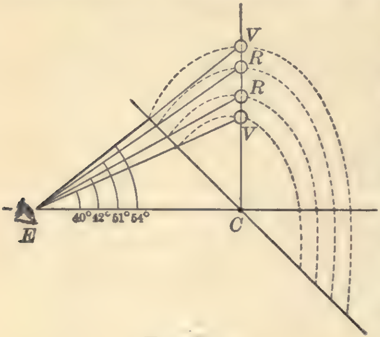


Fig. 464.

494. Color. — We have seen that the amount of refraction that a ray undergoes when passing through a prism is dependent upon its wave length. We have also seen that different amounts of refraction give rise to different colors when white light falls upon the prism. We may, then, define *color* as a property of light that depends upon its wave length.

495. The Color of Opaque Bodies is determined by their relative power of absorbing and reflecting certain wave lengths. A body that absorbs all the colors except red, reflects that color and is red.

Experiment 244. — Paste a strip of white paper upon a black card and, holding it in the sunlight, examine it by looking through a prism. The edges of the paper will give the spectrum colors. Examine in the same way strips of red and blue paper, and the spectrum in each case will give only the color that the paper reflects.

Experiment 245. — Paste a strip of white paper, 10 in. long and $\frac{1}{4}$ in. wide, on a black card. Paste, at right angles to this, pieces $\frac{1}{8}$ in. wide and 2 in. long. Place a prism as in Fig. 465, and examine the strips. The spectra of the narrow strips into which we may suppose the long strip to be divided, will overlap and give white light except

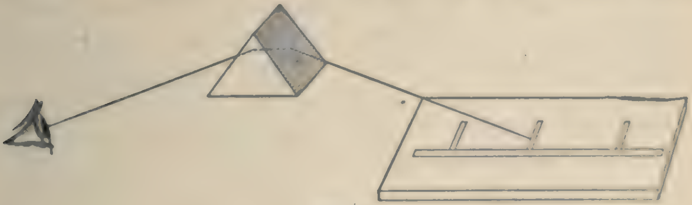


FIG. 465

at the ends, one end being red and the other violet. The spectrum of each narrow line will be a complete spectrum.

If the color that a body reflects is red, it will not appear red unless the light that shines upon it has red in it.

EXPERIMENT 246. — Take slips of differently colored paper into a dark room and examine them under the light from a photographer's lamp, giving a ruby red light, or under the yellow light from a candle upon which some salt has been sprinkled.

This experiment shows the importance of selecting colors under the same light as that in which they are to be used. A color that is exactly suitable by daylight may have an entirely different appearance by gaslight.

496. The Color of Transparent Bodies (viewed by transmitted light) depends upon the color that they transmit. If a body transmits all colors equally, it is colorless. If it transmits one color only, — yellow, for example, — then it will have that color; but if it transmits several, its color will be that which results from combining the transmitted colors in the relative amounts in which they are transmitted.

497. Newton's Disk. — Sir Isaac Newton used a method of combining colors that depends upon the principle of *persistence of vision* in the eye. If a cardboard disk is painted red on one sector and yellow on the other, as in *A* (Fig. 466), and if it is then rapidly rotated on an axis passing through the middle of the disk, the color will appear to the eye to be orange. This is purely a physiological result, the red sensation following the yellow sensation so quickly that the result is a combination of the two. If violet and red are used instead of yellow and red, the result will be purple. Combinations of any colors, in any proportions, can be made by having a disk of each color slit radially, as *B* in Fig. 466, so that they can be slipped over one another while on the axis.

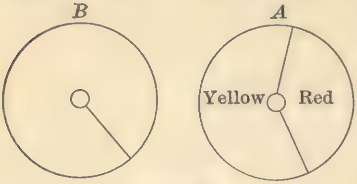


FIG. 466

498. Complementary Colors. — If blue and orange are used in the right proportions in Newton's disk, the resulting effect will be practically white. Two colors which, added together, produce white, are called *complementary colors.*

A chart, like that shown in Fig. 467, is convenient for showing complementary colors. It is so arranged that the combination of the two colors opposite will produce white. The various shades and tints of these colors can be formed by combining two or more colors in different proportions.

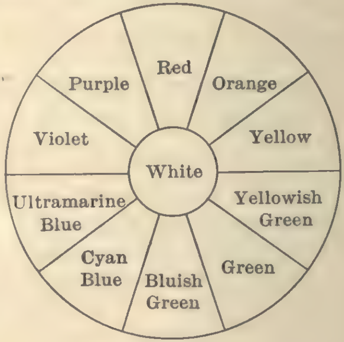


FIG. 467

Complementary colors frequently give pleasing effects when used near each other, as in the arrangement of ribbons, flowers, and leaves.

EXPERIMENT 247. — Place a square of any bright color in a brilliant light and look at it steadily for a minute or two. Turn the eyes upon a piece of white paper, and a square of the same size, but of the complementary color, will be seen.

The constant looking at a certain color in this experiment seems to render the retina less sensitive to the same color in white light, hence the complementary color is seen.

499. Mixing Pigment Colors. — The results obtained above have been obtained by mixing spectrum colors. The same results will not be obtained by mixing pigments. A mixture of yellow and blue color produces white, but a mixture of yellow and blue pigments gives green.

500. The Spectroscope is an instrument for the production and study of the spectra from different sources. It has three essential parts, which are shown in diagram in Fig. 468.

The *collimator* C is provided with a slit at the end nearest the light L, and a lens so arranged that the light will pass from the collimator to the prism in parallel lines.

The prism P is fixed in such a position that the refracted beam passes through it and emerges in the direction PT. The telescope T is movable, and can be focused on any ray that emerges from the prism. A general view of one form of the instrument is shown in Fig. 469.

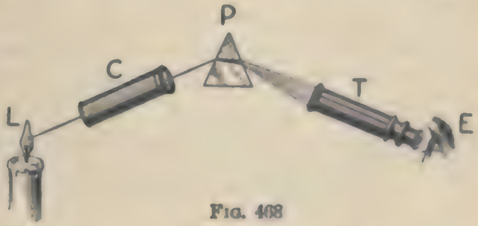


FIG. 468

501. Spectrum Analysis. — The kind of spectrum that is given by any source of light depends upon the physical condition of the source. There are three kinds of spectra: the *continuous spectrum*, the *bright line spectrum*, and the *absorption* or *dark line spectrum.*

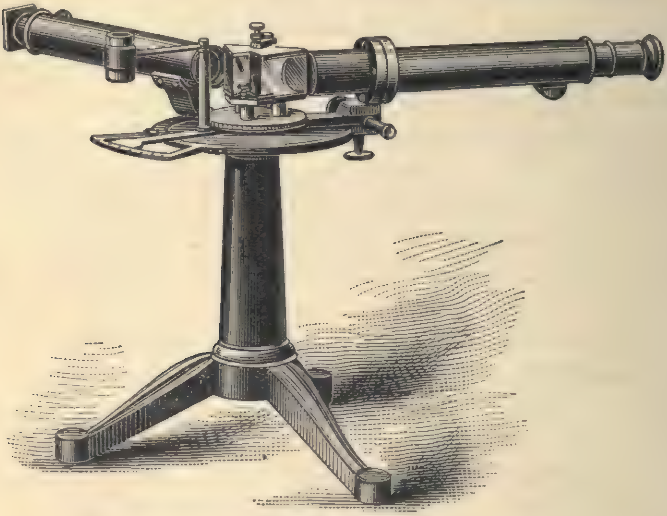


FIG. 469

EXPERIMENT 248. — Examine the flame of a candle by the spectroscope, and it will be seen to be continuous from the red end to the violet, passing through all the intermediate colors by imperceptible gradations.

502. First Law of the Spectrum. — *When the source of light is an incandescent solid, liquid, or dense gas, the spectrum is continuous.*

The continuous spectrum in Experiment 248 is the spectrum of incandescent carbon from the candle. The same kind of spectrum is obtained from a lamp or gaslight.

EXPERIMENT 249. — Dip a platinum wire in a solution of salt and hold it in a Bunsen flame. Examine the flame with the spectroscope, and instead of a continuous spectrum, a bright yellow band will be seen in the middle of the place occupied by the yellow of the continuous spectrum. (A small ball of cotton or lamp wicking on the end of a wire can be used in place of the platinum wire.)

This yellow band is called the *sodium line* or *D line*, and on being closely studied is seen to be made up of two narrow lines with a dark band between them.

503. Second Law of the Spectrum. — *Incandescent gases, not under great pressure, give a spectrum made up of bright colored lines on a dark background.*

Each line has a definite position in the spectrum, and is characteristic of the substance which produces it.

EXPERIMENT 250. — Examine sunlight by the spectroscope, and the colored spectrum will be seen to be crossed by a series of dark lines. Moisten a platinum wire with a solution of salt and hold it in a Bunsen flame in front of the slit. One of the dark lines, the *D* line, will be made darker. Shut out the sunlight and examine the sodium flame alone, and the *D* line will show in the same place as a bright yellow line.

We see in this experiment that the passage of sunlight through sodium vapor — itself capable of giving a bright line — intensifies the dark line in the solar spectrum. The fact that this dark line is in the same place as the bright line does not mean that there is no sodium in the sun, but instead means that the sodium vapor in the sun's atmosphere absorbs the light of the same wave length as that given out by incandescent sodium, and makes this part of the spectrum look dark in comparison with the rest of it.

504. Third Law of the Spectrum. — *The vapor of any substance will absorb the light given out by the same substance in a state of incandescence.*

Such spectra are *absorption spectra.*

505. Fraunhofer Lines. — The dark lines described above are called the *Fraunhofer lines*, and on account of their invariable position are used as standards of wave length. A careful study shows that there are 377 bright lines in the spectrum of iron that exactly coincide with the same number of dark lines in the solar spectrum. The conclusion follows that *iron exists in the atmosphere of the sun in a state of vapor.*

The positions of the most prominent of the Fraunhofer lines are shown in Fig. 470, in which the violet end of the spectrum is at the right.

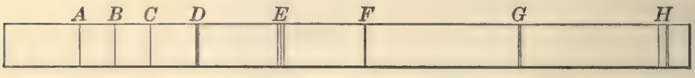


Fig. 470

The accompanying table gives the wave lengths of some of the dark lines of the spectrum. There are parts of the visible spectrum in the red end that have longer wave lengths than the *A* line, as well as parts in the violet that have shorter wave lengths than the *H* line. A comparison of these shows that the wave length for red light is about twice that for violet.

Line	Color	Wave Length in mm.
A	Dark Red	.0007594
B	Red	.0006870
C	Orange	.0006563
D_1	Yellow	.0005896
D_2	Yellow	.0005890
E_1	Light Green	.0005270
b_1	Dark Green	.0005184
F	Blue	.0004861
G	Dark Blue	.0004308
H	Violet	.0003968

506. The Invisible Spectrum. — The visible spectrum is by no means the limit of the dispersion secured by the prism. Beyond the red are a series of longer waves that can easily be detected as *heat rays*, while beyond the violet are shorter waves that have great chemical activity, and are called the *chemical* or *actinic rays.*

EXPERIMENT 251. — Cut a piece of photographic printing paper into strips and pin them end to end upon the wall of a dark room so as to form a long strip. By means of a prism throw the solar spectrum upon the middle of the strip, which should extend a third of its length beyond each end of the spectrum. Mark the position of every color and the end of the visible spectrum. After a short exposure notice that the greatest effect on the paper is at the violet end of the spectrum or just beyond it, and that at the red end there is practically no change.

507. Doppler's Principle applied to Light Waves. — The position of the dark lines of the spectrum is invariable only when the distance between the source of light and the observer is fixed. If this distance is regularly diminishing, the wave length corresponding to a given line diminishes, and if it is increasing, the wave length increases.

If the spectrum of a star is examined, and it is found that the *C* line, for instance, is located at the right of the position of that line in the solar spectrum, as the lighter line in Fig. 471, the explanation is that the star is moving toward us and thus shortening the wave length that produces the line. If the displacement is toward the red end of the spectrum, then the star is receding from us. Since the velocity of the star determines the amount of this displacement, a measurement of this amount can be used as a basis for calculating the velocity of the star's motion.

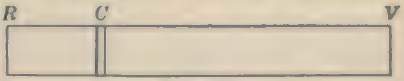


FIG. 471

508. Interference. — We have already seen the results of interference in sound waves. Two waves may meet in such a way as to strengthen each other or to neutralize each other. Similar phenomena occur in light, as is shown in the following experiment.

EXPERIMENT 252. — Against a piece of plate glass press the curved side of a plano-convex lens with great focal length. On looking at the upper surface of the lens at an angle, a series of concentric circles will be seen, each one of which will be made up of the colors of the spectrum. If a sheet of red glass is placed between the lens and the light, so that light of that color alone falls upon the lens, the rings will be alternate dark and red bands.

These rings are called *Newton's rings.* The colors seen on looking at a thin film of oil on water, a soap bubble, or a crack in a piece of ice, are examples of interference.

509. Explanation of Newton's Rings. — When light strikes the lens the refracted ray is partly reflected at *A* and its phase is changed. Some other refracted ray will be reflected from *B* (without change of phase) and will pass into the air in the same path as the first, *CD*. If the distance *AB* is a quarter wave length the reflected rays are in the same phase and give light, but if it is a half wave length the reflected rays are in opposite phases and there is interference or darkness. As the space between the curved surface of the lens and the plane glass increases gradually, there is a distance that corresponds to a quarter wave length for every color of the spectrum.

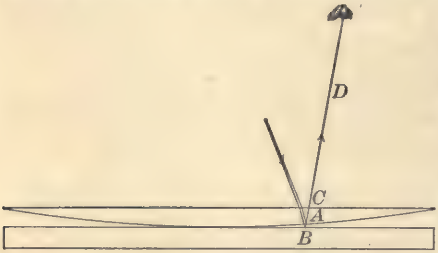


FIG. 472

510. Diffraction. — EXPERIMENT 253. — Expose a photographic dry plate to daylight. Develop and fix it. Wash thoroughly and dry. With a fine needle or the point of a knife blade draw a series of parallel lines through the film to the glass. Hold this plate close to the eye and look through it at the flame of a candle. There will be seen brilliant spectrum colors extending on either side of the flame.

EXPERIMENT 254. — On one half of the plate used above, draw two sets of parallel lines at right angles to each other, dividing the film into small squares. Look through this at an arc or incandescent light, and fine lines of spectra will be seen to extend at right angles from the light.

A fine silk handkerchief gives a good effect when looked through, especially when the light examined is an arc light. A plate of glass upon which a little lycopodium powder has been sprinkled gives a series of beautiful rainbow effects when a candle or any bright light is seen through it. The cause of these phenomena is that rays of light on passing through a narrow slit spread out into a diverging band, or are *diffracted*, and if the edges of the slit are near each other interference takes place and gives colored fringes.

The *diffraction grating* consists of from 10,000 to 20,000 parallel lines to the inch, ruled on glass or on speculum metal. If on the former, the light passes through, if on the latter, it is reflected from the polished and ruled surface. Spectra of wide dispersion can be obtained from such gratings, and they are used in place of the prism in spectroscopic work. The spectrum given by the grating is called the *normal spectrum*, since in it the distribution of the different wave lengths is uniform.

511. Polarized Light. — The vibrations of the ether that produce a ray of light are transverse vibrations. If the circle in Fig. 473 is taken to represent a cross section of a ray of light, the vibrations set up in the ether are shown not only as transverse, but as transverse in every direction. If all the vibrations were parallel transversely, as in Fig. 474, then the ray would be a ray of *plane polarized light*.

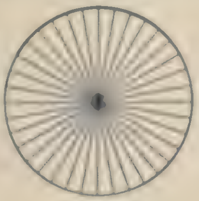


FIG. 473

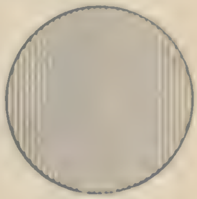


FIG. 474

Polarized light presents to the eye nothing to distinguish it from ordinary light, but it presents certain very interesting phenomena when studied under stated conditions. The crystal tourmaline has the property of permitting vibrations in only one plane to emerge from it; that is, it polarizes light.

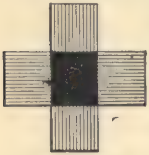


FIG. 475

EXPERIMENT 255. — Place two tourmaline crystals one over the other and parallel to each other. The light that passes through one will pass through the other. Now turn one of them until it crosses the other at right angles, as in Fig. 475, and no light at all passes through the crossed portion. The action is as though each let through only those vibrations which are parallel to its length. Now put between the tourmalines a piece of quartz or Iceland spar, and on turning one of the tourmalines brilliant colored effects are observed. The effect of the quartz, then, must be to turn the plane of polarization and to enable a part of the light to pass through the second tourmaline.

512. Double Refraction. — If a crystal of Iceland spar is placed upon a sheet of paper on which there is a black dot, the eye placed above the spar will see two dots, one a short distance from the other and apparently above the surface of the paper. This action of Iceland spar upon light is called *double refraction*. One of these rays, the upper in Fig. 476, obeys the ordinary laws of refraction and is called the *ordinary ray;* the other does not obey these laws and is called the *extraordinary ray.* Another peculiarity of these rays is that they are polarized.

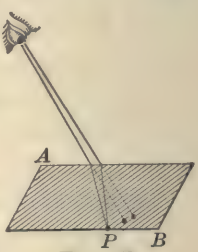


FIG. 476

If a crystal of Iceland spar is cut along the diagonal AB (Fig. 476), and then cemented together again with Canada balsam, it has the property of permitting only the extraordinary ray to emerge. This is called a Nicol's prism and is much used in the study of polarized light.

EXPERIMENT 256. — Lay a sheet of black paper upon the table. Over this lay a sheet of glass *G* (Fig. 477). Cut out about a dozen pieces of thin glass, and holding them as at *A* in the figure, look through them at a piece of mica *M* laid upon the glass sheet. Hold the thin glasses at various angles and elevations, and determine the position in which the most brilliant effects are produced.

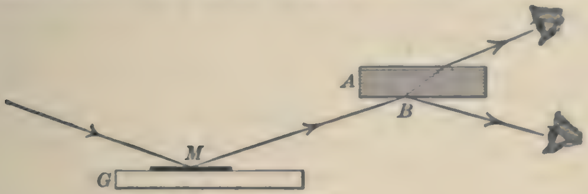


FIG. 477

The study of substances by polarized light has become a matter of great importance, since it reveals differences in physical structure that cannot be discovered by other means. The same results are obtained if the eye is placed below the glasses in such a position that the polarized ray is reflected from *B*.

PRACTICAL QUESTIONS AND PROBLEMS

1. Make a drawing of a prism, the refractive angle *A* of which is 60°, and trace the path of a ray from *L* as it passes through and out of the prism. Using the same incident ray *L*, increase the angle *A* by 10° successively and show the change in the emerging ray until it no longer emerges from the side *AC*. Where does the ray emerge?

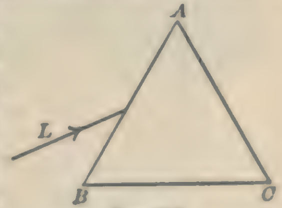


FIG. 478

2. What is the reason that the outside of the image of a landscape formed by a single lens is indistinct? What is the remedy? Why is it sometimes colored? What is the remedy for this?

3. Why is the rainbow circular? Why do we not see the entire circle?

4. Do the different colors in the rainbow, seen by an observer, come from the same or different drops? Prove your answer by a drawing.

5. Suppose you were examining the light from a distant body with a spectroscope, what conclusions would you draw about the body if the spectrum were continuous? If it were crossed by dark lines? If it were made up of bright lines?

6. Taking the velocity of light as 186,000 mi. per second and the wave length of yellow light from the table on page 424, find how many waves of this color strike the eye per second.

7. Suppose that in the spectrum of light from a star it is found that the *D* line is displaced toward the violet end of the spectrum. What is the meaning of the displacement?

8. Why, when looking at the moon through a screen door, do we see four diverging streamers of light? What direction do they take? Why?

LABORATORY WORK

1. Take a prism into a dark room and place in such a position that a ray of sunlight passing through a slit in the shutter will be thrown as a spectrum upon the wall. Mark the position of the ends of the spectrum and take the measurements necessary to measure the angle of dispersion. Make a drawing of the experiment to scale.

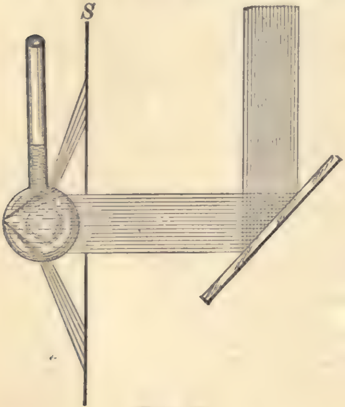


FIG. 479

2. Make a hole in the middle of a black cardboard screen, and directly in front of it suspend the bulb of an air thermometer filled with water. Throw a beam of sunlight through the screen and study the circular rainbow thrown back upon it. Fix the bulb at different distances from the screen and determine the angle between the incident and emergent rays. Cover certain portions of the bulb and determine the part of the surface necessary to produce the bow. Make drawings of the paths of the rays and compare with Fig. 461.

3. Lay upon the table two pieces of colored paper, as red and yellow, at *A* and *B* (Fig. 480). At *C*, midway between them, support a piece of plate glass vertically. Place the eye at *E*, and look at *A* through the glass in such a way that the reflection from *B* will be seen in the same place. Study the effect of different colors combined in this way.

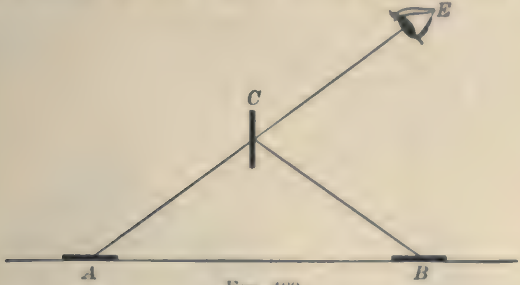


FIG. 480

4. By the use of a rotating wheel such as is shown in Fig. 481 and a set of color disks, match different pieces of colored ribbon or paper. Make a table of the colors used and the relative amounts of each. This wheel is so arranged that the proportion of each color used can be read off on a graduated circle outside the color disks.

5. Locate with the spectroscope the bright lines given off by burning sodium and lithium in a Bunsen flame. Note their color. Burn different compounds in the flame and notice whether you can detect the presence of either sodium or lithium.

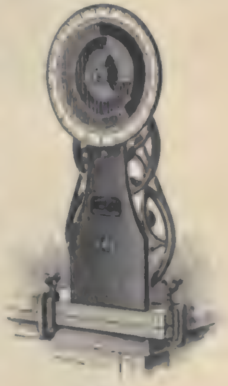


FIG. 481

6. Select two pieces of glass that are not flat, and place them in a photographic printing frame, with their convex sides together, and a piece of black paper between the glass and the cover of the printing frame. Change the pressure and observe the corresponding change in the interference phenomena.

7. Make a simple polariscope as follows. Take a baseboard *AB* (Fig. 482), about a foot long, and at one end set up a ground glass screen *C*. Lay a sheet of black paper upon the base, and over it lay a glass plate *D*. Fix an arm *E* by a brace *H*, making an angle of about 35° with *AB*. At the upper end fasten the piece *K*, and at *L* set in a piece of plate glass. Bore a hole through the middle of *K*, and put through it a brass tube carrying a Nicol's prism. Set this in such a place that the light can come in through *C* and be reflected from *D*.

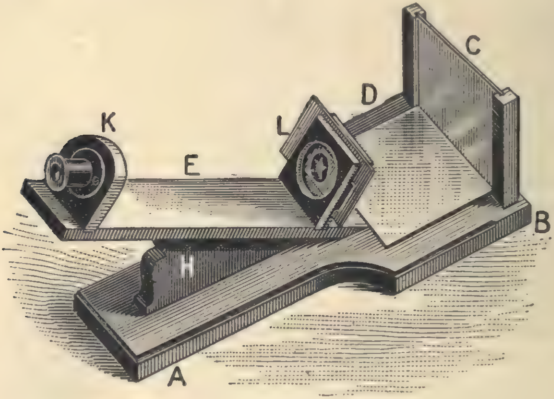


Fig. 482

Examine thin sheets of mica, selenite, quartz, etc., by supporting them on the shelf *L* and looking at them through the Nicol's prism, turning them while you look. Beautiful effects can be obtained from mica cut at different thicknesses. Examine the glass stoppers of bottles, especially the part that has been pressed for a handle while the glass was hot. The existence of dark spots while the Nicol is turned means that the glass is in a strained condition, and liable to break on receiving a light blow.

8. Put between a photographic negative and the printing paper a sheet of transparent red celluloid, from which a circular disk has been cut. Print this in the usual way and observe the effect of the celluloid.

Make the experiment with celluloid of the different spectrum colors and determine the relative actinic values of the colors.

V. OPTICAL INSTRUMENTS

513. The Simple Microscope is merely a convex lens, usually of short focal length. The object is placed between the principal focus and the lens, and the image is virtual, upright, and larger than the object. If the object *AB* (Fig. 483) is placed as shown, the position of the image of the point *A* is determined by the intersection, at *A′*, of *aF′* and *AO*. (See § 480.) *B′* is found in a similar way, and the positions of these two points determine the position of the whole image.

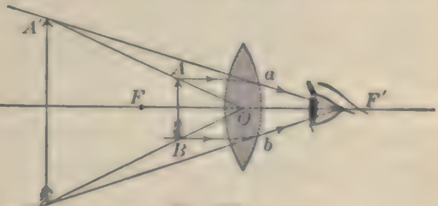


FIG. 483

514. The Compound Microscope (Fig. 484). — The simplest form of the compound microscope consists of two

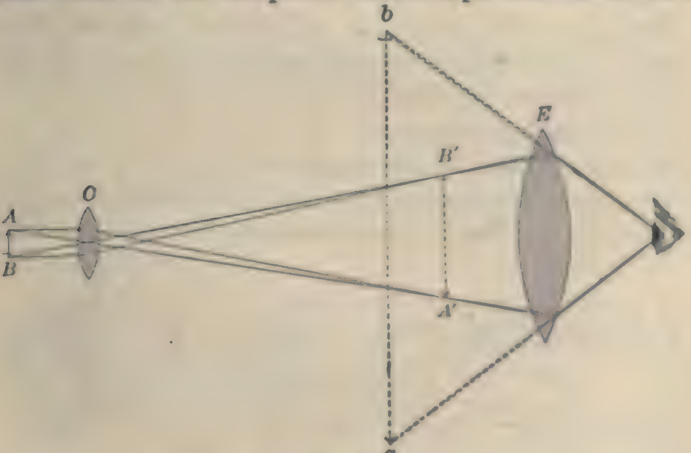


FIG. 484

converging lenses, an *object glass O*, and an *eyepiece E*. The distance between these is so arranged that the object glass forms a real, enlarged, inverted image of the object between the eyepiece and its focus. The function of the eyepiece is to enlarge this image, so that the eye sees the enlarged and inverted image at *ab*.

515. The Astronomical Telescope. — The ordinary astronomical telescope (refracting) is much like the compound microscope in principle. But while both lenses magnify in the microscope, owing to the nearness of the object to the object glass, the eyepiece alone magnifies in the telescope. This is due to the fact that the object is at a distance, and the image formed by the object glass is nearly at its principal focus and very small.

516. The Terrestrial Telescope. — The image given by the astronomical telescope is an inverted one. This is not very objectionable when one is looking at the heavenly bodies; but it is more convenient, in a telescope to be used on objects on the surface of the earth, to have the image erect. This result is secured by putting two converging lenses between the object glass and the eyepiece.

517. Galileo's Telescope; the Opera Glass. — The simplest form of telescope is *Galileo's telescope*. This has but two lenses: a convex object glass and a concave eyepiece (Fig. 485). The eyepiece is placed between the object

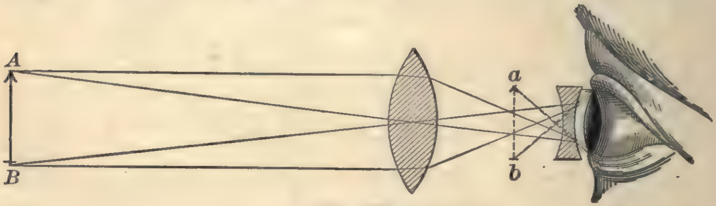


FIG. 485

glass and the image formed by it. Being concave, the eyepiece causes the rays to diverge and appear to the eye to come from *ab*, which thus forms an enlarged upright image. Opera glasses consist of a pair of these telescopes.

518. The Optical Lantern is used for the purpose of throwing an enlarged picture of a lantern slide upon a screen. The essential parts are some brilliant source of light, as the lime cylinder *L* (Fig. 486), a condensing lens *G* formed of two plano-convex lenses with curved surfaces toward each other, a glass lantern slide *S*, upon which is the picture to be enlarged, and a projecting lens *P*, a combination of lenses for enlarging the picture. The arc light is often used as a source of light, and sometimes an oil lamp, though this is inferior to the others. When the lime light is used the lime cylinder is raised to incandescence by the heat from an oxyhydrogen blowpipe.

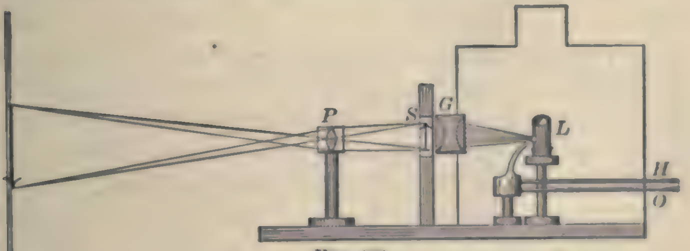


FIG. 486

519. The Camera, used in photography, consists of a light-tight box having at one end an achromatic lens and at the other a ground glass plate and a space in which a plateholder containing a sensitized plate can be placed. In order to regulate the amount of light passing through the lens and to increase the distinctness by cutting off the

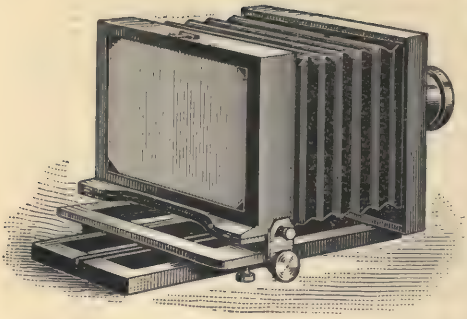


FIG. 487

outside rays, the lens is provided with a series of diaphragms with different-sized openings. The camera is so constructed that the distance between its ends can be varied. By making this distance right the image is brought to a fôcus on the ground glass, then the sensitized plate is put in its place and the exposure is made. The plate is afterward developed by means of certain chemicals. This process reduces the silver salts in the film to a metallic condition, forming a dark layer wherever the light has acted. The salt that has not been acted upon by the light is dissolved out by putting the plate in a solution of hyposulphite of sodium, after which the plate is washed and dried. The plate is now called a *negative*, and prints can be made from it upon sensitized paper.

520. The Eye as an Optical Instrument. — The eye is a minute camera, with dark chamber, lens, and screen upon which the image is formed. The sclerotic coat S (Fig. 488) forms the wall of the dark chamber, and is extended in front as a transparent coat called the *cornea* (C). The lens of the eye is formed of an elastic, transparent substance, and is called the *crystalline lens*. It is held in place by the suspensory ligament and separates the eye into two chambers, that in front of the lens being filled with a colorless transparent fluid called the *aqueous humor*, while the larger chamber behind it is filled with a jelly-like substance called the *vitreous humor*. Extending over the front of the lens is a colored curtain, the *iris*, which determines the color of the eye, and which has a circular opening in the center called the *pupil*. The image of an object is brought to a focus upon the inner lining of the eye called the *retina*, from which the sensation of sight is carried to the brain by means of the optic nerve. The yellow spot Y is the most sensitive part of the retina, and, since it is on the axis of the eye, is the point on which the image of the particular thing we are looking at is formed.

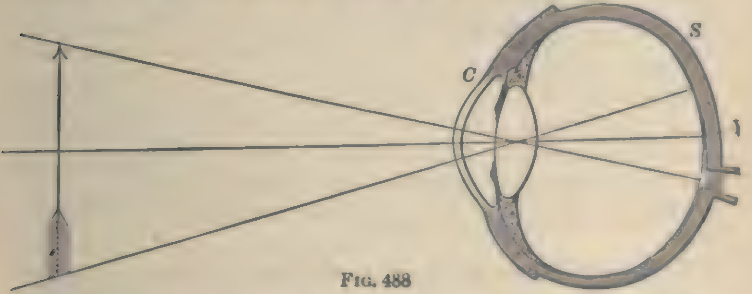


Fig. 488

We have seen that in the camera either the lens or the ground glass must be movable in order that a focus may be found for objects at different distances. The distance between the crystalline lens and the retina, however, is a fixed distance, and the focus is obtained by a change in the curvature of the front of the lens, thus changing its focal length. This property of the lens to change its focus for objects at different distances is called *accommodation.*

521. The Blind Spot. — At the inner side of each eye where the optic nerve enters there is a *blind spot*. This can be readily proved as follows: Close the left eye and look steadily at the cross on this page with the right. A position for the book can be found in which, while you

+ O

look steadily at the cross, the circle will disappear. When this position is found the circle may be brought into view by moving the book either nearer to the eye or farther away.

522. The perfect adaptability of the retina of the eye as a screen for receiving the image formed is shown as follows:

Experiment 257. — Fix a convex lens in the shutter of a dark room. Place a white paper screen in such a position that the middle of the image of the landscape will be in focus. The edges will be blurred and indistinct. Now bend the screen into the arc of a circle, and all parts of the picture on a horizontal axis will be equally distinct.

This experiment shows that the entire field of view in the eye is made distinct by the spherical form of the retina.

APPENDIX

ADDITIONAL LABORATORY WORK

1. *Weight of Unit Volume of a Substance.* — Saw out a cherry block about 3 in. square and 1 in. thick and boil it in paraffin. Weigh the block in both grams and ounces. Take four measurements of each dimension at the edges of the block. Take the average of each set of four measurements for the true dimensions. From these dimensions compute the volume of the block both in cubic centimeters and in cubic inches. Calculate the weight of one cubic centimeter and of one cubic inch of the block.

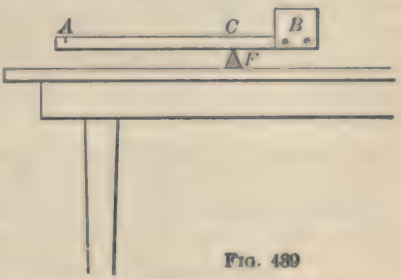


FIG. 489

2. *Center of Gravity and Weight of a Lever.* — Screw a small block (*B*, Fig. 489) to one end of a straight lever about two feet long. Make a saw cut near *A* with a thin-bladed saw. Cut out a block, *F*, with a triangular cross section and so locate it that the lever will remain in a horizontal position when balanced upon one of the edges of the block. When it is in that position make a mark directly over the edge of the fulcrum and measure its distance from the end of the lever at *A*. This gives the distance of the center of gravity from *A*.

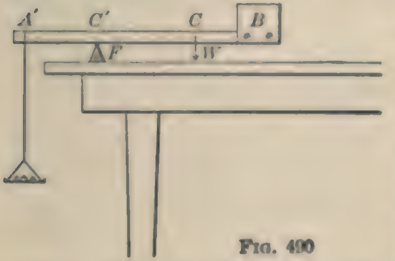


FIG. 490

Placing the fulcrum block near the edge of the table, balance the lever upon it by suspending a scale pan and weights from a cord in the notch A' (Fig. 490). Calling the weight of the lever W, and that of the scale pan, suspension, and small weights w, find the weight of the lever from the expression $W = w\frac{A'C'}{CC'}$. Verify by weighing on a spring scale.

3. *Levers of the Second and Third Classes.* — Bore a small hole through the 50-cm. mark on a meter stick and support the stick on a wire nail driven into a post. If necessary, wind a few turns of copper wire upon one end of this stick and slide them along until the stick comes to rest in a horizontal line. Suspend a scale pan and weights from some scale division, as 30, by a loop of strong thread, and from some other division, as 5, bring the lever to a horizontal position by attaching a spring balance. Make a record of the balance reading, weight, and distances, and from these verify the law for levers of the second class. Repeat with different weights and measures.

Make the experiment with the spring balance nearer to the fulcrum than the point of suspension of the weights, and verify the law for levers of the third class.

4. *Errors of a Spring Balance.* — Suspend the balance from some suitable point by the ring handle and take a zero reading, that is, observe whether the pointer reads zero with no load. Suspend weights, ounces or grams, that are like the numbered divisions on the balance scale, from the hook of the balance. Make a record of the true loads and the readings on the scale, and from these make an error curve. To do this, lay off on cross-section paper a horizontal line to represent the readings of the scale and from this lay off the errors, the + errors above the line and the − errors below. Preserve this curve for future reference.

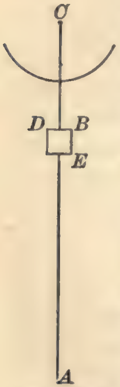


FIG. 491

Repeat the experiment, suspending the scale by the hook.

Determine the horizontal error by placing the scale on horizontal supports, face up, jarring the scale to overcome friction, and taking the zero reading.

5. *Images formed by a Convex Cylindrical Mirror.* — Draw a straight line lengthwise on a sheet of paper and lay it on a table. Stand a cylindrical mirror upon the line with its center of curvature at *C*. Place a small cube on the line as shown in Fig. 491. Study the image of the cube as seen from above the other end of the line at *A*. Put a mark on the corner *B* and answer the following questions:

Is the image real or virtual?

What directions do the images of the sides *BD* and *BE* take?

Are the images larger or smaller than the object?

Repeat the experiment with the cube at different distances from the mirror.

6. *Images formed by a Concave Cylindrical Mirror.* — Repeat the experiment with a concave cylindrical mirror, and write answers to the same questions.

7. *Virtual Image formed by a Lens.* — Set up a diverging lens in a vertical plane, and behind it, at such a distance that the image of its whole length can be seen in the lens, a foot rule, *AB* (Fig. 492). Place a second rule at *D* between the eye and the lens. With the eye a measured distance above the table look toward *AB* and read on the scale *D* where the line of sight from *AB* cuts it, and also where the line of sight from the image of *AB* cuts it. Measure all distances and make a drawing to scale. Change the distance of the eye from the table, repeat the measurements, and transfer the results to the drawing. Is the image real or virtual? Is it larger or smaller than the object? Is it upright or inverted?

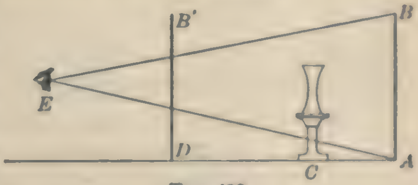


FIG. 492

8. *Four Forces at Right Angles in One Plane.* — Lay off on the surface of a board, made like a drawing board, with crosspieces at the end, any convenient number of small squares, and at the corners of each square drill a hole of the proper size to admit a large wire nail. Place the board on a number of bicycle balls upon a table. Put nails in four of the holes and attach to each of them a cord to which a spring balance is hooked. Apply a pull to each balance until the cords are parallel to the sides of the squares and the board is in equilibrium. Make a drawing to represent the board. Draw a line to represent the point of application, intensity, and direction of each pull. Construct the resultants of the forces taken two at a time, and find the direction and intensity of each.

9. *Comparison of Masses by Acceleration Test.* — Since $F = Ma$ (Formula 8, page 40), one means of comparing the masses of bodies is to compare the velocities that are obtained on subjecting these masses to the action of equal forces. To make this comparison, cut from a small rubber tube a piece about two feet long, and attach each end to a small carriage that runs with little friction. Tack a long strip of paper to the table and draw a line four feet long on it and then short cross lines at each end and at the middle. Attach a cord to the rear of each carriage and after pulling them apart pass the cords over two small pulleys and tie them together as shown in Fig. 493. Load each carriage and burn the cord at *A*. Observe where the collision occurs. Vary the load in one of the carriages until this takes place at *C*, midway between them. When this occurs the masses should be equal. Verify by weighing each carriage and its load.

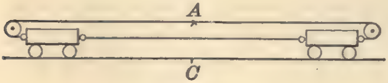


Fig. 493

10. *Action and Reaction: Elastic Collision.* — Suspend two celluloid balls, *A* and *B*, of different diameters, in such a way that they will just touch each other in a horizontal line when at rest. Draw *A* to one side a measured distance and let it fall against *B*. The release can be made by fastening a short thread to *A* with a bit of wax, on the side opposite to *B*, tying it to a hook in the support, and then burning the thread. Do this a number of times and from the average of the measured distances through which the balls move, and their masses, found by weighing, find whether the total momentum after

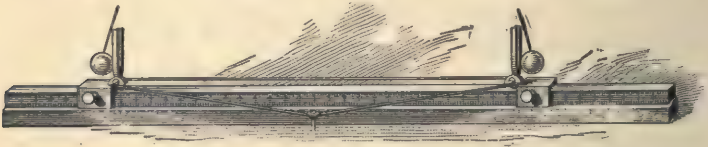


Fig. 494

collision is the same as before collision. To do this, represent the momentum of a ball by the product of its mass and the distance through which it moves. Repeat with *A* stationary and *B* drawn aside. Vary the experiment by drawing both balls aside, using an arrangement like that shown in Fig. 494 for simultaneous release.

11. *Action and Reaction: Inelastic Collision.* — Repeat No. 10 after sticking a band of putty around one or both the balls. Observe and make a record of the different results and explain the reason for the difference.

12. *Increase of Pressure of a Gas heated at Constant Volume.* — A glass tube *AD* is closed at one end and connected by means of a rubber tube with a second tube *EF*. The part *AB* of this tube is filled with dry air, while the rest of the tube, *BD*, the rubber connecting tube, and a part of the tube *EF* are filled with mercury. To find the volume of the air at zero the part *AB* is thrust through a cork that fits the opening in the bottom of the cylinder *H*. The cylinder is then filled with water with ice in it and the point *B* is kept at the bottom of the cork *K*. When the position of *B* remains unchanged, and *C* is at the same level as *B*, measure the distance *BD*. Remove the ice from the cylinder, let the water run out by taking out the plug *P*, put on the cover, and connect *S* to a source of steam. Keep the distance *AB* constant by raising the tube *EF*, and measure the distance of *C* above *B* when the steam pours freely from the opening at *P*, and *AB* shows no further tendency to increase in length. Read the barometer and from the data obtained find the increase in pressure per degree of temperature.

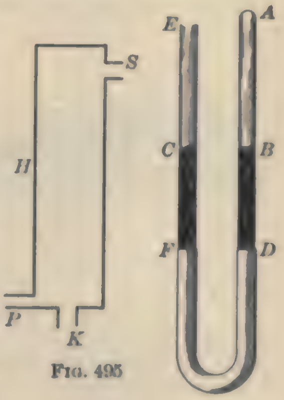


FIG. 495

13. *Increase of Volume of a Gas heated at Constant Pressure.* — With the air at zero, determine the position of the end of the mercury column the same as in the first part of No. 12. Replace the ice water by steam as before, but thrust the tube *AD* further into the steam cylinder through *K*, keeping the surface of the mercury just in sight.

Also, keep the mercury levels C and B in the same horizontal line by lowering EF. When the air column shows no further increase, the barometer and the new distance BD (or $B'D$) must be read. From the data obtained, determine the amount of expansion of dry air per degree of change of temperature. This is the coefficient of expansion of volume at constant pressure. In order that the volume of the tube may be proportional to its length, a tube must be selected of uniform internal diameter.

14. *Number of Vibrations of a Tuning Fork.* — Arrange a tuning fork so that it shall trace its vibrations on a piece of smoked glass, and support a short pendulum so that it shall vibrate close to the end of the fork. The pendulum, like the fork, must be provided with a stylus as shown in Fig. 496, and on being vibrated it will trace transverse lines on the smoked glass. Count the number of vibrations made by the pendulum per minute. Put both the fork and the pendulum into vibration and draw the smoked glass under them. Count the vibrations recorded by the fork between two intersections of the traces of both fork and pendulum, and from these numbers compute the number of vibrations of the fork per second.

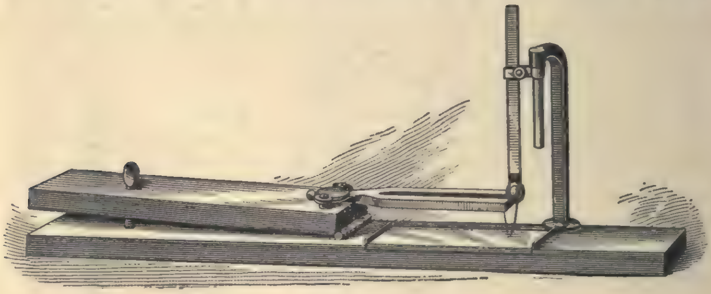


FIG. 496

15. *Study of a Single-fluid Galvanic Cell.* — Make up a small copper-zinc cell with dilute sulphuric acid. Place the metals in the acid and observe any action at their surfaces. Couple them to a galvanometer and observe whether there is any change in the action at these surfaces. Observe and make a record of the deflection of the galvanometer. Remove the zinc from the cell and amalgamate it with mercury. Repeat the experiment with the amalgamated zinc and make a record of the observations.

16. *Study of a Two-fluid Galvanic Cell.* — Make up a Daniell cell as follows: Place a strip of amalgamated zinc in a solution of dilute sulphuric acid in a porous cup. Outside the porous cup place a copper plate in a saturated solution of copper sulphate. Couple the cell to a galvanometer and notice the deflection. Remove both the zinc and the copper from the cell, and weigh separately after the liquids have drained off. Replace the plates in the cell and close the circuit for a half hour. Weigh each plate again and make a record of the change in weight of each and of the deflection of the needle of the galvanometer. Explain.

17. *Lines of Force about a Galvanometer.* — Couple a cell, switch, and the tangent galvanometer (Fig. 325) in circuit as shown in Fig. 497, placing the coils of the galvanometer in the magnetic meridian. Lay a large sheet of cross-section paper on the table with one set of lines in the magnetic meridian and place the galvanometer stand in the middle of it. Send a current through the circuit, and, holding a small compass in the hand at the same level as the middle of the galvanometer, observe the direction that the needle takes in different positions around the galvanometer. Transfer these positions to the cross-section paper and draw the directions of the lines of force.

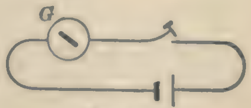


FIG. 497

Increase the current by using two cells and repeat.

Turn the galvanometer so that the coils are at a right angle to the magnetic meridian and repeat the experiments. Explain the results.

18. *Resistance of Wires by Substitution: Different Lengths.* — Apply the method of Experiment 195 to wires of the same material and cross section but of different lengths.

19. *Change of Resistance with Change of Temperature.* — Wind a coil of fine German silver wire around a wooden spool in such a way that its turns do not come in contact. Submerge the coil in a beaker of ice-cold water and measure its resistance on the Wheatstone bridge. Submerge the coil in a beaker of hot water and measure the resistance again. Take the temperature of the water in both cases, and compute the change of resistance for a change of one degree in temperature.

20. *Electric Motor.* — Assemble the parts of a small motor that may be run by a battery, and operate it. Couple a voltmeter to the terminals of the motor, take readings at different speeds, and observe that the "back electro-motive force" increases with the speed. Couple an ammeter in series with the motor and observe the effect of an increase of speed upon the current.

21. *The Dynamo.* — Assemble the parts of a small dynamo. Run it at the proper speed; couple it to a voltmeter, and measure the voltage. Prove that the voltage depends upon the speed by running the dynamo at a slower speed and again measuring the voltage.

ANSWERS TO NUMERICAL PROBLEMS

Page 15. — **1.** 7.74 m. **2.** 241.5 km. **3.** 44 ft. .39 in. **4.** 39.68 lb.

Page 16. — **5.** (*a*) 1417.4 g., (*b*) 1.4174 kg. **6.** (*a*) 1.944 l., (*b*) 1.944 kg. **7.** 39.79 cm.

Page 52. — **4.** (*a*) 250 ft., (*b*) 32.5 ft., (*c*) 50 ft. per second. **6.** 15,000. **7.** 4,900,000. **8.** 321.6 poundals. **9.** 562.5 ft. per second. **10.** 355.5 ft. **11.** 86.02 lb., a little west of southwest. **12.** 15 min. **13.** 20 min. 7.5 sec. diagonally upstream.

Page 53. — **14.** 30.57 ft. per second, a little north of northeast. **15.** Resultant = 28.3 lb., a little south of southeast. **16.** $\frac{3}{8}$ of its length from the end. **17.** 4 ft. from one end. **18.** 11.79 mi. **19.** 32.3 lb. **20.** 55.97 lb.

Page 67. — **1.** 37,800. **2.** 1936 foot poundals. **3.** 5005. **4.** 10,602 foot pounds. **5.** 288,000 foot pounds. **6.** 135,360 foot pounds.

Page 68. — **7.** (*a*) 58,060,800 foot pounds, (*b*) 8.06 H.P. **8.** .609 H.P. **9.** 1 hr. 26.8 min. **10.** (*a*) 375 foot pounds, (*b*) 375 foot pounds. **11.** 4,212,985 foot pounds. **12.** 20.41 kilogrammeters. **14.** (*a*) 6, (*b*) 6.4.

Page 69. — **16.** 157 lb. **19.** (*a*) 3198.2 foot pounds, (*b*) 4924.5 foot pounds. **20.** 352,000.

Page 83. — **2.** (*a*) 578.88 ft., (*b*) 112.56 ft., (*c*) 192.96 ft. per second. **3.** (*a*) 325.62 ft., (*b*) 128.64 ft., (*c*) 360 ft. **4.** 1790.6 ft. **5.** 15,840 foot pounds. **6.** 100.5 ft. **7.** 6120 ft. **8.** (*a*) 4.5 sec., (*b*) 325.62 ft. **9.** 8.95 in. **10.** (*a*) 40 ft., (*b*) 20 ft. per second. **11.** 23.9 cm. **13.** 87.96 in. **14.** 1.108 sec.

Page 84. — **18.** 99.45 cm.

Page 101. — **3.** Downward, 22.25 units to the right of F.; upward, 22.25 units to the left of F. **4.** 696 lb.* **5.** 12.885 ft. from F.

Page 102. — **9.** 4 ft. **10.** 63 in. **12.** $5333\frac{1}{3}$ lb.* **13.** 17.86 lb.* **14** (*a*) 32.14 lb.,* (*b*) 525 ft. **15.** 122.22 ft. **16.** (*a*) $2\frac{1}{4}$, (*b*) 16.40 ft., (*c*) 53.4.

Page 103. — **19.** (*a*) $\frac{1}{12}$ of the weight, (*b*) .976 of the weight. **20.** $116\frac{2}{3}$ lb.* **22.** 33,929.3 lb.* **23.** 6. **24.** $89\frac{1}{4}$%. **25.** .625.

Page 127. — **1.** (*a*) 2160 lb., (*b*) 76.39 lb. **2.** 10 lb.* **4.** (*a*) 750 lb. (*b*) 562.5 lb., (*c*) 281.25 lb. **5.** (*a*) 500 lb., (*b*) 250 lb., (*c*) 125 lb. **6.** 54 lb. **7.** 3563.75 tons. **8.** 3515.625 lb.

Page 128. — **9.** 65.1 lb. **10.** (*a*) 52 kg., (*b*) 980.6 g. **11.** (*a*) 378 g., (*b*) 756 g., (*c*) 1512 g. **12.** (*a*) 9375 lb., (*b*) 28,125 lb. **13.** (*a*) 13,000 kg., (*b*) 50,000 kg., (*c*) 12,000 kg., (*d*) 75,000 kg. **14.** 73.63 lb. **15.** 147.46 ft. **16.** 281,250 lb. **17.** $5\frac{1}{4}$ ft. from top. **18.** 2 ft. from top. **19.** 753.98 g. **20.** 592.48 g. **21.** (*a*) 2500 g., (*b*) 9216 g.

Page 136. — **3.** (*a*) 350 lb., (*b*) 2.8. **4.** (*a*) 2.84, (*b*) 150 c.c.

* The answers for problems in machines are given for equilibrium. To produce motion the friction of the machine must be overcome also.

5. Top, 11,400 g.; bottom, 13,200 g.; side, 6150 g.; end, 2952 g. **7.** 11.43. **8.** 374.61 kg. **9.** (*a*) 12,766.5 lb., (*b*) 1,595,812.5 foot pounds. **10.** 64.24 g. **11.** 366.5 lb. **12.** 2.65. **13.** .874. **14.** 1.841. **15.** 1.42.

Page 137. — **16.** 95.24 g. **17.** 16.8 cm. **18.** .48. **19.** (*a*) 8.7, (*b*) 8.346, (*c*) 8.64, (*d*) 8.356.

Page 159. — **1.** 506.67 mm. **2.** (*a*) 424.12 lb., (*b*) 106.03 lb. in each direction. **3.** (*a*) 12,960 lb., (*b*) 17,280 lb., (*c*) 25,920 lb. **4.** 58.185 kg. **5.** 5.61 m. **6.** 992.5 g. **7.** 576 cu. in.

Page 160. — **8.** (*a*) 812.52 cm., (*b*) 10.8 mm. **9.** 43,200 lb. **10.** 7991.5 m., or about 5 mi. **11.** 105 in. **12.** 3.21 atmospheres. **13.** 33.2 ft. **17.** $\frac{81}{256}$.

Page 172. — **4.** 6825 ft. **5.** 12.1 sec. **6.** .61 sec. **7.** (*a*) 2.84 sec., (*b*) .41 sec. **9.** 8.

Page 188. — **2.** 7.68 in. **3.** 337.9 m. per second. **5.** 4. **7.** (*a*) 8, (*b*) *g*, *e*, and *c*. **8.** 133 per second before, 123 per second after.

Page 189. — **12.** At least 20,515 lb.

Page 202. — **1.** 48 cm. **2.** 2 m.

Page 203. — **3.** $2\frac{2}{3}$ ft. from end. **4.** 2.34 lb. **6.** 2.4 ft.

Page 212. — **1.** $25\frac{1}{5}$°. **2.** $20\frac{5}{9}$°. **3.** (*a*) $73\frac{2}{5}$° F., (*b*) $24\frac{4}{5}$° F., (*c*) $-9\frac{2}{5}$° F. **4.** (*a*) $20\frac{5}{9}$° C., (*b*) -5° C., (*c*) $-22\frac{2}{9}$° C.

Page 213. — **5.** -40°. **7.** 234.2°. **8.** (*a*) $491\frac{2}{5}$°, (*b*) $459\frac{2}{5}$°.

Page 235. — **1.** .054 in. **4.** 677.68 c.c. **7.** 3125 lb.

Page 236. — **10.** 102.3° C. **11.** 63.5° C.

Page 241. — **3.** 36.6°. **4.** 87.7°. **5.** .109. **6.** $6\frac{2}{3}$ kg.

Page 242. — **7.** 13 lb. **8.** 12.27 lb. **9.** 2.71 kg. **10.** 5736. **11.** (*a*) 83.08 calories, (*b*) raise it to 10.385°. **12.** 1250. **13.** 93.11 g. **14.** 28°. **15.** 23.64°. **16.** 32.03°. **17.** 22.97°. **18.** Raise it to 19.09°.

Page 291. — **11.** 18.66 sec.

Page 304. — **1.** .184 amp. **2.** .124 amp. **3.** .341 amp. **4.** .143 amp. **5.** (*a*) 1.326 amp., (*b*) 2.28 amp.

Page 313. — **1.** 777,600. **2.** 47,520 lesser calories. **3.** 25.38°. **4.** 4.21 amp. **5.** 4.75 g.

Page 330. — **1.** 3 hr. 32 min. 23 sec. **2.** 18 min. 38 sec. **3.** 10.62 ohms. **4.** 64.53 ohms. **5.** (*a*) 110 ohms, (*b*) $73\frac{1}{3}$ ohms, (*c*) 55 ohms, (*d*) 44 ohms. **6.** 5.09 ohms.

Page 331. — **7.** 2.51 ohms. **8.** 4.29 ohms. **9.** 3.52 ohms. **10.** (*a*) 55 watts, (*b*) 3.44 watts. **11.** (*a*) 1.1 amp., (*b*) 45.45 ohms. **12.** 450. **13.** 29.5. **14.** (*a*) 360, (*b*) 17.78 ohms, (*c*) 6.67 ohms.

Page 369. — **8.** 5.09 ohms. **9.** (*a*) 127.25 ohms, (*b*) 135.73 ohms, (*c*) 1192.77 volts, (*d*) 10,305 watts, (*e*) 427.68 watts.

Page 370. — **10.** 36. **11.** (*a*) 17.78 ohms, (*b*) 6.67 ohms. **12.** 1.25 ohms. **13.** (*a*) 427.5, (*b*) 47. **14.** (*a*) .52 amp., (*b*) 52 watts, (*c*) 3.25 watts. **15.** (*a*) 1.04 amp., (*b*) 48.08 ohms. **16.** 5.1 ohms. **17.** (*a*) 3.2 volts, (*b*) .328 ohms, (*c*) 7,257,600 lesser calories. **18.** (*a*) 21,000 watts, (*b*) 1000 watts. **19.** (*a*) 13 amp., (*b*) 213 amp., (*c*) 200 amp.

Page 371. — **20.** 39. **21.** 11,000,000.

Page 379. — **5.** 8 min. 18 sec. **6.** About 285,000.

Page 380. — **7.** 7.11. **8.** 576. **10.** 41.42 ft. from one and 58.58 ft. from the other. **11.** 24 ft. **12.** 15 ft.

Page 411. — **11.** 3.9 in. **12.** 72 cm.

Page 430. — **6.** About 500 trillions.

FORMULAS

PAGE	SUBJECT	FORMULA	NUMBER
38	Velocity	$S = vt$	1
		$\therefore \quad v = \frac{S}{t}, \qquad t = \frac{S}{v}$	
38	Acceleration	$v = at$	2
		$\therefore \quad a = \frac{v}{t}, \qquad t = \frac{v}{a}$	
38		$S = \frac{1}{2} at^2$	3
		$\therefore \quad a = \frac{2S}{t^2}, \qquad t = \sqrt{\frac{2S}{a}}$	
38		$S = \frac{v^2}{2a}$	4
38		$v = \sqrt{2aS}$	5
39		$s = \frac{1}{2} a(2t - 1)$	6
39	Momentum	$h = Mv$	7
40	Force	$F = Ma$	8
50	Centrifugal Force	$F_c = \frac{Mv^2}{r}$	9
50		$F_c = \frac{Wv^2}{gr}$	10
56	Work	$\text{Work} = FS$	11
57	Horse Power	$H.P. = \frac{\text{Foot pounds}}{33000 \times \text{minutes}}$	12
58	Energy	$P.E. = Wh$	13
58		$K.E. = \frac{1}{2} Mv^2$	14
58		$K.E. = \frac{Wv^2}{2g}$	15

Page	Subject	Formula	Number
60	Attraction	$F_g = \frac{MM'}{d^2} a$	16
62	Weight above surface of earth	$W : w = d^2 : D^2$	17
63	Weight below surface of earth	$W : w = D : d$	18
71	Falling bodies having initial velocity	$v = V + at$	19
		or $v = V + gt$	
74	Falling bodies from position of rest	$v = gt$	20
74		$s = \frac{1}{2} g(2t - 1)$	21
74		$S = \frac{1}{2} gt^2$	22
79	Simple Pendulum	$t = 2\pi\sqrt{\frac{l}{g}}$	23
80		$t : t' = \sqrt{l} : \sqrt{l'}$	24
88	General Law of Machines	$Fd = RD$	25
91	Lever	$P : R = R.$ arm : $P.$ arm	26
92	Balance with unequal arms	$W = \sqrt{W'W''}$	27
93	Wheel and Axle (power applied to wheel)	$P : W = r : R$	28
95	Fixed Pulley	$P = W$	29
95	Movable Pulley	$P = \frac{1}{2} W$	30
96	System of Pulleys	$P = \frac{W}{n}$	31
	Inclined Plane:		
97	Power parallel to L,	$P : W = H : L$	32
97	Power parallel to B,	$P : W = H : B$	33
99	Wedge	$P : W = \frac{1}{2} T : L$	34
100	Screw	$P : W = p : 2\pi R$	35
101	Coefficient of Friction	$f = \frac{P}{W}$	36
124	Liquid Pressure	$P = HaW$	37
132	Specific Gravity of Solids	Sp. Gr. $= \frac{W}{W - W'}$	38
150	Homogeneous Atmosphere	$H = \frac{P}{W}$	39

Page	Subject	Formula	Number
150	Boyle's Law	$VP = V'P'$	40
169	Velocity of Sound in Air	$v = 332.4\sqrt{1 + .003665t}$	41
170	Velocity of Sound in any Gas	$v = \frac{332.4}{\sqrt{d}}$	42
170	Velocity of Sound in any Medium	$v = \sqrt{\frac{e}{d}}$	43
176	Velocity and Wave Length	$v = NL$	44
177	Velocity from Resonance Tube	$v = 4\,N(l + r)$	45
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210		$F = \frac{9}{5}C + 32°$	47
225	Linear Expansion	$L' = L(1 + Kt)$	48
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302	In series coupling	$C = \frac{SE}{Sb + R}$	53
302	In parallel coupling	$C = \frac{E}{\frac{b}{P} + R}$	54
303	In series and parallel	$C = \frac{SE}{\frac{Sb}{P} + R}$	55
306	Heating Effects of Current	$H = .24\,C^2Rt$	56
318	Resistance of Conductors	$R = K\frac{l}{d^2}$	57
328	Combined Resistances of Parallel Circuits	$R = \frac{gs}{g + s}$	58
369	E.M.F. of Dynamo	$E = \frac{nCN}{10^8}$	59
407	Focal Length of Convex Lenses	$\frac{1}{f} = \frac{1}{p} + \frac{1}{p'}$	60

TABLE OF CONVERSION FACTORS

TO CHANGE	TO	MULTIPLY BY
Inches	Centimeters	2.54
Feet	Meters	.305
Miles	Kilometers	1.609
Meters	Inches	39.37
Kilometers	Miles	.621
Square inches	Square centimeters	6.452
Square yards	Square meters	.836
Square centimeters	Square inches	.155
Square meters	Square yards	1.196
Cubic inches	Cubic centimeters	16.387
Cubic yards	Cubic meters	.765
Cubic centimeters	Cubic inches	.061
Cubic meters	Cubic yards	1.308
Fluid ounces	Cubic centimeters	29.57
Quarts	Liters	.946
Cubic centimeters	Fluid ounces	.034
Liters	Quarts	1.057
Grains	Milligrams	64.799
Ounces (Avoirdupois)	Grams	28.35
Pounds (Avoirdupois)	Kilograms	.454
Ounces (Apothecary)	Grams	31.103
Pounds (Apothecary)	Kilograms	.373
Grams	Grains	15.432
Kilograms	Pounds	2.205

TABLE OF SPECIFIC GRAVITIES

Aluminum, cast	2.57	Mercury	13.596
Copper, cast	8.88	Nickel	8.60
Gold, cast	19.30	Platinum	21.45
Iron, cast	7.08	Silver, cast	10.45
Iron, wrought	7.85	Tin, cast	7.29
Lead, cast	11.34	Zinc, cast	7.10

WIRE TABLE (COPPER)

Temperature = 75° F. Sp. Gr. = 8.89.

No.	Diam. in Mils*	Ohms per 1000 feet †	Feet per Pound	No.	Diam. in Mils*	Ohms per 1000 feet †	Feet per Pound
1	289.3	.12	3.95	14	64.1	2.59	80.59
2	257.6	.16	4.99	15	57.1	3.12	101.63
3	229.4	.20	6.29	16	50.8	4.02	128.14
4	204.3	.25	7.93	17	45.3	5.07	161.59
5	181.9	.31	10.00	18	40.3	6.39	203.76
6	162.0	.40	12.61	19	35.4	8.29	264.26
7	144.3	.50	15.90	20	32.0	10.16	324.00
8	128.5	.63	20.05	21	28.5	12.82	408.56
9	114.4	.79	25.28	22	25.4	16.15	515.15
10	101.9	1.00	31.38	23	22.6	20.38	649.66
11	90.7	1.26	40.20	24	20.1	25.70	819.21
12	80.8	1.59	50.69	25	17.9	32.40	1032.96
13	72.0	2.00	63.91	30	10.0	103.30	3293.97

* Mil is a thousandth of an inch.

† The resistance column may be extended by observing that twice the resistance of any number is approximately the resistance of the third number further on in the table; *e.g.* the resistance for No. 10 is 1 ohm, for No. 13 is 2 ohms, for No. 16 is 4.02 ohms, etc.

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